HANDBOOK

OF

PLANT MORPHOLOGY

BEING THE

HANDBOOK OF PLANT DISSECTION

BY

J. C. ARTHUR, CHARLES R. BARNES
AND JOHN M. COULTER

REVISED AND REWRITTEN

BY

OTIS W. CALDWELL, PH.D.
Professor of Botany in the Eastern Illinois State Normal School

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ANNOUNCEMENT.

SINCE 1886, when the *Handbook of Plant Dissection* was published, both the methods of laboratory work and knowledge of the plant kingdom have very materially changed. The authors thought that any demand for the book would have disappeared long since, but continued sales have forced them to the conclusion that in justice to the subject and also to themselves a revision is necessary. In morphological instruction the very detailed study of a few types has given place to a study of the most significant features of a considerable number of types; and the accumulation of somewhat unrelated facts has been succeeded by the attempt to organize the facts into a connected account of the evolution of the plant kingdom.

An adequate revision, therefore, meant a complete rewriting, and this the original authors were unable to undertake. Accordingly they have delegated it to one whose contact with laboratory work in elementary morphology is fresher and has proved to be in every way successful.

The book is a new one, although developed in accordance with the old plans, and it will far more worthily

supply the demand that seems to exist than could an edition long since out of date.

J. C. ARTHUR.
C. R. BARNES.
J. M. COULTER.

March 10, 1904.

AUTHOR'S PREFACE.

In the preparation of these outlines it is recognized that a given set of directions is not completely adequate for the work of any two teachers, nor even for one teacher's use during two consecutive years. A good instructor is the chief determinant in a course of study. In his hands the materials, the laboratory, and the book become efficient in the presentation of the subject. To his students the laboratory guide serves as an outline to which he makes additions as determined by the immediate needs of his own class. It is rather generally recognized that a course of study in botany may be made much stronger if a well-organized plan is placed before the students, since a good instructor can make requisite eliminations and additions to fit his peculiar needs, and all by means of the laboratory guide may have the advantage of the accumulated experience of others. The wide field of usefulness that was filled by *Plant Dissection* furnishes abundant evidence as to the value of a good laboratory guide. It was in response to a belief that a new book which embodies the general arrangement and some of the important principles of the old one will be correspondingly useful, that the authors of *Plant Dissection* suggested the preparation of this work.

The outlines here included, subject to variations necessitated by peculiarities of local environment, have been used by the writer in courses given in the University of Chicago, the Biological Station of the University of Indiana, and the Eastern Illinois State Normal School. In addition to this test of use the manuscript has been read and improved in very important ways by the authors of *Plant Dissection*, and by Professor F. E. Lloyd of Teachers College, New York, and Professor F. L. Stevens of the State Agricultural College, Raleigh, N. C., to all of whom grateful acknowledgments are made.

OTIS W. CALDWELL.

THE EASTERN ILLINOIS STATE NORMAL SCHOOL,
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CONTENTS.

INTRODUCTION.

I. Point of view.

In preceding school work the student is expected to have obtained some general notions as to what plants are, and as to the way in which they are adjusted to environment in structure and habit. In the organization of a more formal course in botany, it is believed that two prominent facts should be kept in mind. First, structures of plants are related and more or less perfectly adapted to the two primary functions of *nutrition* and *reproduction*. Second, there has been throughout the history of the plant kingdom a gradual evolution of plants as their structures have become progressively better adapted to the two phases of plant work. In the general course in botany plant structures are considered from the point of view of what they have to do in nutrition and reproduction, and with reference to the general problem of evolution of the plant kingdom. In tracing out these two lines of plant activity a considerable knowledge of individual plants and of the various groups of plants will be obtained.

The general course in botany should not be planned primarily with the idea of training specialists in the subject, but should present those essential principles of plant life that are adapted to the needs of the general student

who may eventually give the major part of his time to botany or to any other subject.

II. Equipment.

The laboratory should be provided with well made unvarnished tables, so placed as to leave ample space for students to move about the room. If good light comes from one or two sides of the room, the best results may be obtained by placing the tables with their ends to the windows. There should be for general use:

1. A supply of good water, distilled water being preferable in many cases.
2. Commercial alcohol or synthol.
3. Formalin.
4. Glycerin.
5. A five per cent solution of potassium hydroxid or sodium hydroxid.
6. Iodin.
7. A cement for ringing mounts. King's, or "gold size" will be satisfactory.
8. Camel's-hair brushes.
9. A turntable.
10. A razor-strop.
11. A hone for sharpening razors, and another for scalpels.
12. Two or three vascula.
13. Glass bottles and jars of various sizes for collecting and preserving specimens.
14. Some large glass jars for growing water-plants in the laboratory.
15. Driers, plant-press, and mounting-paper.

In addition to these things in many laboratories it is quite desirable to add materials with which specially prepared permanent mounts are made. Such a list should include:[1]

16. A microtome.
17. An imbedding-oven.
18. Paraffin.
19. Various reagents, as xylol, clove-oil, bergamot-oil, cedar-oil, absolute alcohol, and Canada balsam.
20. Stains, as Delafield's hæmatoxylin, cyanin, erythrosin, iron alum, bismarck brown, etc.
21. Glassware designed especially for work in staining and mounting microtome sections.

Each student will need:

22. Hand-lens, or dissecting-microscope.
23. Compound microscope.
24. Razor.
25. Small pair of forceps.
26. Dissecting-needles.
27. Medicine-dropper, or pipette.
28. Syracuse watch-glass, or other small glass dish.
29. Glass slides and cover-slips.
30. Blotting or filter paper.
31. A clean soft cloth for cleaning the microscope and drying slides and cover-slips; also lens-paper for cleaning the lenses.
32. Drawing materials, consisting of good paper and a medium hard pencil. A fine pen such as a lithographic pen and India ink may be added with profit.

[1] For complete list of things needed see Chamberlain's "Methods in Plant Histology."

III. How to use the laboratory.

1. *Hand-lenses and compound microscope.*—All that can be determined concerning the specimen in hand without magnification should be done before use is made of magnifying-glasses. The use of hand or dissecting lenses and the compound microscope should never be considered an end in itself, but merely a means of obtaining a better idea of plants than is possible without these things.

A prime requisite in the use of any optical instrument is cleanliness; dirty lenses frequently defeat the very object of their use, namely, clearer vision. Before beginning to work with any lens, see that it is perfectly clean. When a lens needs cleaning a camel's-hair brush may first be used to brush away any particles of dust. Then wipe gently with a piece of lens-paper or unstarched linen or cotton, breathing first upon the lens to moisten the dirt. Too great care cannot be taken to avoid scratching the polished surface of the lens; hence in wiping it the least possible effective pressure should be used. If properly handled after once thoroughly cleaned, lenses will seldom need any cleaning except brushing. One should avoid touching the lens with the fingers, since the oil from the skin adheres to the glass and temporarily impairs its usefulness. Such spots may be removed by wiping with linen *slightly* moistened with alcohol. In using the compound microscope the front only of the objectives and both surfaces of both lenses of the eyepieces need cleaning. If the eyepiece be dirty, there will be specks in the field of view when there is no object upon the stage. These can be made more apparent by

turning the eyepiece in the tube while looking through it. In like manner by partly unscrewing the eye-lens and turning it, one may discover whether the eye-lens or field-lens is dirty. If the front lens be dirty, it will be shown by a dimness and want of definition of the outlines of objects, thus affecting the whole field of view.

In focusing, use first the low-power objective. By using the rack and pinion adjustment lower the objective well down toward the cover-slip. Then while looking into the eyepiece, after having made sure that the best light is reflected by the mirror up through the diaphragm in the stage, slowly raise the objective until the object comes into view. When it is desired to use the high-power objective, carefully lower it until it is almost in contact with the cover-slip. Then while looking into the eyepiece focus upward until the object is seen clearly.

Some nosepieces are so constructed that when the low power is in focus the high power may be turned directly into focus without changing the elevation of the objectives. In no case should one focus downward while looking into the eyepiece unless the object is already in view. Failure to observe this caution may result in forcing an objective down upon the slide. Also, before placing or removing a slide the low-power objective should be turned into position for use.

Before leaving the laboratory at the close of a laboratory period, make sure that all the instruments are thoroughly clean and dry and in their proper places.

2. *Illustrative material.* — In studying plants in the laboratory it must always be kept in mind that one should find out as much as he can about the structures and their

relation to life habits, without the use of special instruments and reagents. The latter things are to be called into use to extend the vision beyond its ordinary limits. If this fact is not kept constantly in mind, the study may easily resolve itself into the mere manipulation of laboratory tools, or a study of the technique of instruments and reagents. A knowledge of these things is helpful to a high degree when their proper use is clearly defined.

Do not dissect specimens or make sections until it is decided in a general way what to look for and where to look for it. Such a general notion is essential to proper orientation of structures.

When specimens are to be mounted one must be careful lest they become dry by evaporation. Water may easily be placed upon a drying specimen that has been mounted, by touching a wet brush or a drop of water from a pipette at the edge of the cover-slip.

Many of the materials for study may be mounted entire. Others will need careful dissection by use of the needles. This dissection will often be made much more easy and far more successful by first boiling the material for one or two minutes in a five per cent solution of potassium hydroxid, then pouring off the liquid and rinsing in water. Still others can be studied only by means of carefully made sections. Some of these sections should be made by use of the microtome, but most of them the student can make by free-hand cutting with a good razor. Very delicate materials may be sectioned by being placed between pieces of pith. More rigid ones may be held free in the hand, or in the hand-microtome.[1]

[1] For methods of killing, imbedding, sectioning, staining, and mounting

In case good mounts are obtained and there is not time sufficient to complete the study before the close of the laboratory period, they may be preserved by replacing the water of the mount by use of a ten per cent solution of glycerin in water. A liberal supply of the solution should be used, since the water evaporates, thus causing a thickening of the glycerin. Mounts so made may be preserved for weeks. When the glycerin has become quite thick these mounts may be made permanent by "ringing" them with cement. To do this first remove the glycerin from about the edge of the cover-slip by use of a cloth dampened in alcohol; then place the slide on the turn-table, and after having put it in motion, apply tangentially to the margin of the cover-slip, by means of a camel's-

the student who expects to do such work should consult Chamberlain's "Methods in Plant Histology" and numerous articles in the "Journal of Applied Microscopy." Specific references will be made later.

Unless the class is to do considerable work in histological technique the laboratory should have ready for use a set of good slides of the more difficult sections called for in the outline. Sections of the following things should be included, and many others may be added with profit:

1. The host plant of the parasite *Albugo*, illustrating the structure and reproduction of the latter.
2. The gametophyte of *Riccia*, showing vegetative structure, sex-organs, and young sporophyte.
3. *Marchantia*, showing vegetative structure of thallus, archegonial and antheridial heads, and stages in development of sporophyte.
4. *Anthoceros* gametophyte and sporophyte.
5. *Porella* branches bearing sex-organs and sporophytes.
6. Moss, showing sex-organs and capsule.
7. *Pteris* or a similar fern, showing leaf, rhizome, sporangia, gametophytes with sex-organs, and young sporophytes.
8. *Marsilia* or *Selaginella*, showing structures of male and female gametophytes.
9. Pine, showing wood, needle-leaf, microsporangia, megasporangia, with gametophytes, and young sporophytes.
10. *Trillium* leaf, root (or onion root), stem, microsporangia, and megasporangia.
11. *Ranunculus*, microsporangia. megasporangia, and stem. *Rumex* will serve as well.

hair brush, a ring of the cement. Place the slide in a horizontal position until the cement is dry. A second and third application of the cement helps to insure perfect firmness.

This method of making permanent mounts will be found useful with many of the lower forms of plants when mounted entire, and with dissections and free-hand sections of the tissues of more complex plants. These specimens may be mounted also in Canada balsam, a method that gives greater permanency, but in some cases the manipulation is more difficult. With microtome sections balsam will be found highly desirable as a mounting substance.

In studying the higher plants there will be found from time to time specimens that illustrate especially well certain structures and adaptations to peculiarities of environment. It will be of advantage to preserve some of these in the form of herbarium specimens. This may be done by drying the plants between heavy blotters especially prepared for the purpose, and afterwards mounting them on heavy paper.

By preserving entire plants and the best prepared slides an individual or a laboratory will soon accumulate a good supply of illustrative material. Both individuals and laboratories, however, must guard against the danger of collecting material that illustrates nothing.

3. *Drawings, notes, etc.* — In the systematic examination of an object two kinds of memoranda, descriptions and drawings, should be made. The value of the former is usually conceded, but that of the latter is often deemed too slight to repay the trouble. The importance

of laboratory drawing is not likely to be too strenuously urged, and the difficulty and tediousness of execution, which will largely disappear with practice, should never be offered as an excuse for its neglect.

Drawings may represent the object with various degrees of completeness. At one extreme is the diagram, which aims only to give relative positions, sizes, and relations of parts. A diagram is often very helpful at the beginning of the study of a specimen. At the other extreme is the drawing that is as close a counterpart of the object seen as the person who draws it is capable of producing.

Drawings may usually be made satisfactorily in outline with but little shading. The best results may be obtained by making definite outlines first by use of a sharp, hard pencil, then tracing the outlines and shading with a fine pen and good ink. The paper used for drawing should be the heaviest linen ledger-paper or (more expensive) bristol-board. A convenient form is had by cutting the paper into pieces four by six inches. Note-paper may be cut of the same size, and the two may be bound temporarily, thus constituting a book to which the student adds at each laboratory period. Such blank laboratory books are sold by reliable dealers.

The approximate amount of magnification, if any, under which the specimen was observed at the time the drawing was made should always be noted in connection with the figure.

Photographs may be useful in illustrating habitats and individual characteristics of plants not readily observed by the class. Both geographical and seasonal distribution of plant life is such that often it is impossible for students

to obtain an adequate idea of the normal environment of the plants under consideration. If in connection with the work, instructor and students who can do so, will make and preserve photographs of different phases of plant life, each laboratory will soon possess a collection that will add much to the general knowledge of the forms studied.[1]

Laboratory notes need not be extensive, but should be clear and definite, and by means of the descriptions contained in them and by their constant reference to drawings, should constitute a brief presentation of the important features of the particular plant in question. The laboratory notes should be made up in the main of things the student has learned during his study of the plants themselves. Field notes may well be included with laboratory notes, but both of these should be kept separate from those made in connection with lectures, recitations, and readings.

4. *Reference reading.*—Throughout the outlines occasional references are made to sources of information upon topics in hand. It will not always be possible for the students to look up these references, and they by no means include all that should be read. Access should be had to some good magazines, such as the *Botanical Gazette*, *Bryologist*, *Journal of Applied Microscopy*,[2] *Plant World*, *Rhodora*, *Torreya*, *Bulletin of the Torrey Botanical Club*, and the Journals of the New York Botanical Gardens.

If the following books are available in the library, the

[1] These photographs may be made into lantern-slides, or slides may be purchased that will illustrate details of plant structures and ecological relations of plants.

[2] The publication of this journal has been discontinued, but the back numbers may be obtained, and are especially helpful.

student will be greatly helped. Some of them for text use are essential to success in the work.

Atkinson, G. F. Elementary Botany. Henry Holt & Co., New York, 1898.

Bailey, L. H. An Elementary Text-book of Botany. The Macmillan Company, New York, 1901.

Barnes, C. R. Plant Life. Henry Holt & Co., New York, 1898.

Barnes, C. R., and Heald, F. G. Analytic Key to the Genera and Species of North American Mosses. The University of Wisconsin, Madison, 1896.

Bergen, J. Y. The Foundations of Botany. Ginn & Co., Boston, 1901.

Britton and Brown. Flora of the Northeastern United States and Canada. Charles Scribner's Sons, New York, 1898.

Campbell, D. H. The Evolution of Plants. The Macmillan Company, New York, 1899.

—— A Universal Text-book of Botany. The Macmillan Company, New York, 1902.

—— Structure and Development of Mosses and Ferns. The Macmillan Company, New York, 1895.

Chamberlain, C. J. Methods in Plant Histology. The University of Chicago Press, Chicago, 1901.

Chapman, A. W. Flora of the Southern States. Cambridge Botanical Supply Co., Cambridge, Mass.

Coulter and Chamberlain. Seed Plants, Part I. Gymnosperms. D. Appleton & Co., New York, 1899.

—— Morphology of Angiosperms. D. Appleton & Co., New York, 1903.

Coulter, J. M. Plant Structures. Revised edition. D. Appleton & Co., New York, 1904.

—— Manual of Rocky Mountain Botany. American Book Co., New York.

DeBary, A. Comparative Morphology, and Biology of the Fungi, Mycetozoa, and Bacteria. The Clarendon Press, Oxford, 1880.

Goebel, K. Organography, Vols. I and II. Oxford, 1900.

—— Outlines of Classification and Special Morphology. Oxford, 1887.

Gray, Asa. Manual of Botany, 6th edition. American Book Co., New York.

Grout, A. J. Mosses with the Hand-lens. Published by the author, New York, 360 Lenox Road, Flatbush, 1900.

Pfeffer, W. The Physiology of Plants, translated by A. J. Ewart. 2 vols. Clarendon Press, Oxford, 1900.

Small, J. K. Flora of the Southeastern States. Published by the author, New York, 1903.

Strasburger, Noll, Schenck, and Schimper. A Text-book of Botany, 2d edition, translated by Long. The Macmillan Company, New York, 1903.

Underwood, L. M. Our Native Ferns and their Allies. Henry Holt & Co., New York.

—— Moulds, Mildews, and Mushrooms. Henry Holt & Co., New York.

There should also be a good collection of separate publications on special topics. The habit should be formed of reading the text discussions upon the topics presented in the laboratory. It will often be found necessary to compare descriptions and to attempt to account for variations and contradictions in the statements made, since in many cases the material observed by the student will not show the same things as did that upon which the text statement was based. It will be found advantageous if the text work is upon definite topics related to the laboratory work, rather than a study of the text chapter by chapter as pre-

sented. The topical study stimulates to examination of several texts.

Separate publications written by various research students upon topics considered in the laboratory are most helpful in any extended study. If, after having studied some particular type or in connection with the study, the student may have access to the published results of some one who has made careful and exact investigation of that topic, he will be prepared to appreciate and assimilate the work and point of view of the special student. Furthermore, such literature will bring the student more nearly to the sources from which text statements are constructed, and will give him a broad view of the field of work found in the study of botany.

Many of these special publications are in foreign languages, but this should not be a serious obstacle to the best students. Any one who expects to do extended work in a biological science will soon find that he must have a reading knowledge of at least German and French, and should begin to familiarize himself with these languages as early as possible.

Acquaintanceship with good botanical magazines has numerous advantages. Much information upon the topics studied is obtained; the general spirit of scientific workers may become gradually transferred to the student as from month to month he associates himself with the writings of these men; a knowledge of who the men are who are active in the subject is desirable and is to be obtained from a study of the literature of the subject.

5. *Collection and preservation of material.*—Although much of the material used must be supplied to the student,

it is important that he should know its home, its general characteristics, and the treatment the material has received in case it has been necessary to preserve it in order to have it in good condition at the time the study is to be made. Usually fresh material is highly desirable. Some of this may be kept growing in the laboratory, and local greenhouses will often supply the things needed when they cannot be found in their natural haunts.

The suggestions as to habitat given at the beginning of the outline upon each topic must be general, and definite knowledge of just where in each locality certain forms are found must be supplied by the instructor and the students' own observations.

When it is found necessary to preserve specimens for future use various methods are available. The simpler forms of plants may be preserved entire in seventy per cent alcohol or two to five per cent formalin. Pieces of more complex plants may be preserved in the same way. Some of the Algæ may be kept fairly well by drying upon a piece of mica, it being necessary only to moisten the specimens when they are to be used, or by use of the glycerin method they may be made into permanent preparations ready for use at any time. Specimens of the higher plants that have ecological value may be made into herbarium mounts by use of a simple plant-press, driers, and mounting-paper. Preservation by means of the more elaborate processes of killing, use of different grades of alcohol, imbedding, etc., will be found fully described in Chamberlain's "Methods in Plant Histology."

6. *Independent work.*—Finally, it should be said that the greatest benefits will result from the study as outlined

if the student does as much of it as he can unassisted. Although at times less ground may thus be covered in a given period, more ability to do scientific work is developed. Through this means the results have the very great value of individuality, rather than the much smaller values that come through the constant attempt at being in conformity with detailed suggestions given by another.

GREEN SLIME.

Pleurococcus viridis.

THALLOPHYTES; ALGÆ; CHLOROPHYCEÆ.

PRELIMINARY.

THE plant selected to illustrate the simplest phase of plant life is found in all parts of the United States, and even throughout the world. It grows upon the surface of various objects, being often so abundant as to give them a conspicuous green color, especially the north side of old fences, barns, and the trunks of trees, becoming more noticeable after a few days of damp weather. There are several other closely related forms that may be used. In fact almost any unicellular green plant will answer, but this is the one most easily found. Pieces of bark or wood bearing *Pleurococcus* plants may be kept dry for use, and will give a fresh appearance when moistened with water, and even retain vitality for a year or two.

This plant belongs to the great group known as Thallophytes, a group that is divided into Algæ and Fungi. The Algæ are characterized by the presence of a green coloring-matter known as chlorophyll. Upon the basis of various combinations of colors made by chlorophyll and other coloring substances, as well as upon cer-

tain other distinctions, the Algæ are further subdivided. One of these subdivisions of the Algæ is the Chlorophyceæ, to which *Pleurococcus* belongs.

To complete the following study it will be necessary to have pieces of wood bearing *Pleurococcus;* iodin; and alcohol.

LABORATORY WORK.

GROSS STRUCTURE.

Taking a fresh specimen, observe:

1. The *color.*
2. The *evenness* with which the plant overspreads the supporting surface.
3. By using the scalpel observe that the plants are easily removed from the surface on which they grow.
4. The *pulverulent appearance*, as if dusted or sanded upon the surface.
5. The appreciable thickness reached in some spots, causing it to separate in scales in a dried specimen.

Place a piece of bark with the *Pleurococcus* in a small quantity of alcohol; after an hour or more notice:

6. The color imparted to the alcohol by the coloring-matter of the plant, the *chlorophyll.*[1]
7. Observe the plants after the chlorophyll has been removed.

MINUTE STRUCTURE.

I. Nutritive or Vegetative Structures.

Mount, and under low power observe:

1. The dust-like particles into which it separates.
2. The various sizes of the particles.

[1] Some less common forms of unicellular Algæ, as well as many more complex ones, are red or purple from additional coloring-matter.

Under high power notice:

3. The individual *cells;* either single or associated in groups.
4. The *size* of the cells; some small, some several times larger. By means of a stage micrometer determine the actual size of a few of the cells.
5. The *shape;* when free, and when in groups.
6. The cell contents; more or less granular, and always green from the presence of chlorophyll.
7. The colorless *cell-wall* surrounding each cell.

Press upon the cover-glass with a back-and-forth movement and the walls of many of the cells and cell families will be ruptured and their contents ejected, when the wall can be studied easily.

Stain a fresh specimen with iodin, and observe:

8. The brownish-yellow color given the contents of the cell, showing the presence of *protoplasm.*
9. The separate chlorophyll bodies,[1] or *chloroplasts.*
10. The *nucleus.*

II. REPRODUCTION.

1. The cell multiplication, or *vegetative* reproduction. Examine various specimens and trace the successive stages in the division of a single cell to form a cell group.
2. Illustrate the various structures, and also method of reproduction, by drawings.

ANNOTATIONS.

Pleurococcus is a unicellular plant, for each cell performs individually the various functions pertaining to plant life; and this is true whether the cells do not separate after division or remain adherent in small colonies.

[1] If the cells are properly stained, they will usually remain green, but of a brighter and more bluish hue.

The essential part of the cell is the protoplasm, a colorless semi-fluid substance, which in this instance is obscured by the green chlorophyll. It is the only really living active agent in this as well as in all other plants. Its presence here is made manifest by the yellowish-brown color given by iodin.

The nucleus is a special organ of the protoplasm to be seen in most plant cells. It is definitely related to the life of the cell, and is an important agent in the process of forming new cells.[1] Chloroplasts are protoplasmic bodies that hold the green pigment chlorophyll. The protoplasm by the aid of the chlorophyll is able to produce, from the simple inorganic substances carbon dioxid and water, certain complex foods such as starches and sugars, a function wanting in all animals, and also wanting in many plants, e.g. Fungi and certain colorless parasites that are not Fungi.

The solid, firm, and nearly colorless cell-wall, consisting essentially of cellulose, is a product of the protoplasm, and serves as a protection to it. The fine granules seen in the protoplasm are largely food materials produced by the cell.

The multiplication of the plant by cell-division is a very common method throughout the vegetable kingdom. The nucleus first divides, thus forming two new nuclei.[2] The proptolasm then divides, a nucleus remaining in each part, and a wall is formed between. The two cells thus produced soon attain the size of the original cell,

[1] These structures are not always made clear by iodin. Chloriodid of zinc serves well to demonstrate them.

[2] Read on "nuclear divisions" in reference texts.

when they in turn divide into two, but usually by a partition at right angles to the last one, and so on. The cells thus formed either soon become separated, or remain mechanically united.

Another method of establishing new plants is by the production of *zoospores*. The protoplasm, either as a whole or divided into several parts, escapes from the cell-wall. Each mass pushes out a pair of delicate filaments or *cilia*, which, moving rapidly back and forth, propel the naked protoplasm through the water. The motion and form being animal-like suggested the name. After a period of activity the zoospores come to rest, draw in or drop off the cilia, secrete a cell-wall, and become ordinary non-motile *Pleurococcus* cells. In some plants the protoplasm does not escape from the cell-wall, but contracts somewhat, cilia are protruded through openings in the wall, and the cell or colony is propelled about. The production of zoospores at a specified time, as for a class demonstration, is attended with so much uncertainty that their study has been omitted from the laboratory work. This method of asexual multiplication will be studied later under more favorable conditions in other plants.

NOSTOC.

THALLOPHYTES; ALGÆ; CYANOPHYCEÆ.

PRELIMINARY.

Nostoc may usually be recognized by means of the dirty bluish- or blackish-green jelly-like masses occurring on damp earth, or on water plants, or in free roundish lumps, either floating or submerged in stagnant water. During periods of greater dryness the jelly-like masses frequently form rather dry and flake-like coatings on the earth at the bottom of pools that are becoming dry. Other members of the Cyanophyceæ, the group of Algæ to which *Nostoc* belongs, are often found in bluish-green jelly-like balls and bear considerable resemblance to the *Nostoc* masses. Such forms are *Glœocapsa*, *Cylindrospermum*, *Clatherocystis*, *Glœotrichia*, and *Rivularia*.

LABORATORY WORK.

GROSS STRUCTURE.

1. Examine one of the colonies, observing:
   a. *Color*, as seen in reflected and in transmitted light.
   b. The *jelly* which encloses the plants.
2. Sketch one of the masses.

MINUTE STRUCTURE.

1. Mount a small piece of the colony, and under low power observe the almost colorless granular jelly in which are seen chains of cells.
2. Note whether there is any regularity in the arrangement of the filaments.
3. Under high power study a filament to determine:
   a. The form and number of cells which compose it.
   b. The attachment of the cells one to another.
   c. The form, position, and number of peculiar enlarged cells, the *heterocysts*.
   d. The relation of the heterocyst to reproduction of the filaments.
   e. The structure of a single cell.
4. Compare several plants with reference to the points suggested in 3.
5. Draw in detail one or two representative filaments.

ANNOTATIONS.

The individual cell of a *Nostoc* plant is oblong, has a distinct cell-wall and granular bluish-green protoplasm. Nuclei are not easily demonstrated, and until recently their existence had been questioned. Each cell is probably independent of its neighbors in nutritive work, though doubtless association with them assists it. It seems probable that *Nostoc* plants absorb some food (organic matter) from the water or earth, for they grow only in situations where this is present. This would remove the necessity of so much food-making by these plants, and would accord with the small amount of chlorophyll in the cells.

While in *Pleurococcus* each plant consists of a single

cell, in *Nostoc* many cells are held together in a row partly by the unbroken portions of their cell-walls and partly by the gelatinous material that envelops them. The jelly is formed by a chemical alteration of the outer parts of the cell-walls. They thus constitute a colony. In *Pleurococcus,* colonies were developed when a number of plants had formed from the division of one individual and the resulting groups had not been disturbed; but in *Nostoc* division occurs in parallel planes only, the cells remain long united, and the jelly serves to hold and protect the entire colony.

In reproduction *Nostoc* differs considerably from the unicellular Algæ. The division of any of the cells in the chain results in the growth of the filament, and not directly in the production of a new chain. Finally, when this chain has become large, heterocysts are formed from certain cells, and through their agency the filament is broken into two or more parts, each of which moves independently and may even creep out of the jelly and start a new colony. Even should one cell be cut off from all others, in favorable conditions it might produce a new filament by successive divisions and may reproduce itself in the normal way.

This plant belongs to a group of Algæ known as Cyanophyceæ. The group is characterized by the presence of phycocyanin, a blue coloring-matter, which together with chlorophyll gives the bluish-green color. The plants in the Cyanophyceæ are all quite simple, few being more complex than *Nostoc,* and some even simpler.

DARK-GREEN SCUM.

Oscillatoria.

THALLOPHYTES; ALGÆ; CYANOPHYCEÆ.

PRELIMINARY.

The color of *Oscillatoria*, almost any species of which may be used, is generally sufficient to enable one to distinguish it at sight. Its dark blue-green cast, like that of *Nostoc*, is in marked contrast with the yellow-green of most other plants which form scums. It is very common on stagnant water, often forming patches of scum thirty centimeters or more in diameter, which, becoming loaded with dust, finally sink to the bottom. It is also very common about watering-troughs, along street gutters, at the outlet of drains, on wet rocks, giving them a slippery surface, on the earth of undisturbed pots in the greenhouse, and in all localities in which the water contains a small amount of decaying organic matter. It can usually be grown indefinitely in an open jar, by supplying water as it evaporates, or with less trouble, when once established, in an unstoppered bottle, in which a small twig or flower-stem is inserted to provide nutriment. The plants are often to be found in winter in as good condition as in summer.

LABORATORY WORK.

GROSS STRUCTURE.

1. Examine a small mass of the living plant that has been allowed to remain undisturbed for several hours in a watch-glass of water. Observe:
   a. The deep blue-green *color.*
   b. The hair-like unbranched *filaments*, radiating from the central mass.
2. Sketch the plants as they appear in the watch-glass.

Pulverize a mass of the plant that has been thoroughly dried, place in a test-tube or vial with nearly twice the bulk of water, and after ten to twenty-four hours observe:

3. The color of the solution when seen by transmitted light, and the very different color by reflected light.

Pour off the supernatant water, add the same amount of alcohol, and after an hour or more observe:

4. The yellow-green color imparted by the *chlorophyll.*

MINUTE STRUCTURE.

I. General Characteristics.

Under low power observe:

1. The *color.*
2. The numerous *filaments* of uniform diameter, destitute of branches.
3. Study the *movements.*

II. The Individual Filament.

Under high power observe:

1. The structure in detail, as follows:
   a. The rounded *extremities* of uninjured filaments.
   b. The outline of an uninjured *apex*, whether attenuated or not, and whether bent to one side or straight.

- *c.* The *partition-walls*, which in optical section are seen as delicate lines crossing the filament and dividing it into very small cells.
- *d.* The comparative *length* and *breadth* of the cells.
- *e.* The granular contents, and their distribution in the cell.[1]
- *f.* The delicate colorless *sheath* to be seen extending beyond the green cells at some torn end of a filament, and on which sometimes may be detected transverse lines indicating the position of the end walls of the cells.

2. The *turgidity* of the cells: notice that
   - *a.* The transverse walls in an uninjured filament are plane, while
   - *b.* The last cells of an injured filament are bulged outward, making the outer transverse walls convex, the pressure from within not being counterbalanced from without.
3. Draw parts of two or more plants.

ANNOTATIONS.

If the structure of *Oscillatoria* be carefully compared with that of *Pleurococcus* and *Nostoc* more points of resemblance will be found than appear at first sight. New cells are formed by the process of division, as in *Pleurococcus* and *Nostoc*, but the partition-walls are always parallel and in one direction, which disposes the cell families in filaments. The individual cells have thin partition-walls, the office of protection being relegated to the sheath. The sheath, which is formed from the outside walls of the cells by a modification of the outer portion, is a structure that is mostly confined to certain groups of the lower plants, although it has some

[1] In some species the granules are collected along the partition-walls.

analogies with the cuticle of the higher plants. The chlorophyll is evenly distributed throughout the protoplasm. The study of the protoplasm and chlorophyll is much obscured by the presence of the peculiar coloring-matter, phycocyanin, characteristic of all the Cyanophyceæ. Phycocyanin is insoluble in alcohol, but soluble in water when the plants are dead; while chlorophyll is soluble in alcohol, but not in water; hence from dead plants water removes the phycocyanin, and alcohol the chlorophyll. This blue color is often seen on the sides of vessels in which *Oscillatoria* has remained so long as to die, and also staining the herbarium sheets on which specimens have been dried.

The cells are kept together chiefly by the investing sheath, into which they are packed. This structure, together with the community of action exhibited in producing the peculiar oscillating and nutating movements, makes it evident that the cells of each filament have a certain dependence upon one another, although at the same time each is capable of independent existence. It may be that the smallness of the cells and the thinness of their walls is in some way correlated with this unity of function. It is not yet definitely known how the movements in *Oscillatoria* are produced.

Turgidity is a characteristic of living cells. It is the chief means by which the soft parts of plants are enabled to keep their form, and otherwise to act normally. It is brought about by the ability of the protoplasm to keep certain substances from escaping through it, while their presence causes water to pass in until a considerable internal pressure is created.

Pleurococcus, *Nostoc*, and *Oscillatoria* represent forms of simple plant life. For convenience of study *Pleurococcus* has been placed first; but in its more highly organized nuclei and chlorophyll bodies, and in its modes of reproduction, it shows a somewhat higher order of development than *Nostoc* and *Oscillatoria*. The latter, however, in the arrangement of its cells offers an excellent introduction to the higher filamentous forms, to be taken up next.[1]

[1] If there is abundant time, it will be found advantageous at this point to take up a study of other representatives of the Cyanophyceæ and unicellular Chlorophyceæ. Several genera of Cyanophyceæ are suggested in connection with the "Preliminary" of *Nostoc* study, p. 21.

ULOTHRIX.

THALLOPHYTES: ALGÆ; CHLOROPHYCEÆ

PRELIMINARY.

SPECIES of *Ulothrix* are found in shallow running water either in streams or along the banks of larger bodies of water. They present the appearance of a bright green fuzzy growth upon the supports on which they grow.[1]

The plants may be distinguished from *Cladophora*, which grows in similar places, by being more slippery, shorter, and by being unbranched. Even with these marks it is not always easy to distinguish some members of the two genera, except under the microscope.[2]

When good material is found, it may be preserved by the ordinary preservatives, or may be kept by drying upon the stones or sticks to which it has grown. This dried material may be made ready for use by placing it in water for a few hours or a day before it is to be used. Such material usually forms reproductive bodies

[1] Occasionally *Ulothrix* plants are found floating in free water.

[2] In some places it may be impossible to locate specimens of this plant. When such is the case, preserved material may be had from a supply house. The form is of especial importance, but if it cannot be obtained, some of the features may be illustrated by the plant *Cladophora.*

soon after being placed in water. Fresh material may usually be made to reproduce itself by keeping it in a shallow dish and placing the dish in the dark. Maintaining an even temperature and slowly increasing the density of the liquid tends to induce zoospore formation in this as well as several other Algæ. Reproductive bodies when formed in such places are set free after the material has been in the light for an hour or two.

LABORATORY WORK.

GROSS STRUCTURE.

Carefully remove some of the plants from their support and observe how firmly they are attached. Place a small mass in a watch-glass, and observe:

1. The color as compared with that of the other plants studied.
2. Whether plants are enclosed in jelly.
3. The feel of the mass.
4. The approximate length of single filaments.

MINUTE STRUCTURE.

I. The Nutritive Plant Body.

With a few plants mounted on a slide, under the low power note:

1. The size and form of the cells.
2. Whether they are held together as in *Nostoc* and *Oscillatoria*.
3. Any peculiarities of the basal and apical cells.[1]

With the high power observe:

4. The form and position of the plastid in each cell.
5. Whether the basal "holdfast" contains a chloroplast.[2]

[1] If the ends are found to consist of broken cells, search for sound specimens.

[2] In most cases the "holdfast" is injured in obtaining the material, consequently it may be impossible to find a good specimen.

6. Stain a few plants with a solution of iodin and try to find the nucleus. In case the chloroplast should contain starch it will usually be stained a dark blue by the iodin. The cytoplasm may also be stained and made more easily seen by this process.
7. Draw a few cells showing details of structure. Also draw the "holdfast," in case one is found.

II. Reproduction.

A. Vegetative.

In connection with the processes of growth the cells divide, thereby increasing the length of the plant. Watch for evidence as to whether these elongated plants may break, thus forming two or more plants.

B. By Spores.[1]

Locate some cells in which the protoplasm has been divided into four or more *zoospores*, and study the *spores*, noting:

1. Their form.
2. The *cilia* at the smaller end. How many?
3. The plastid within the spore.
4. How the zoospores escape from the cell in which they are formed.
5. Try to find some of the zoospore-like bodies that are uniting in pairs thus forming sexual spores.

In a dish of material which has been standing for some days will usually be seen a ring of young plants adhering to the glass at the surface of the water. Remove and mount some of this material Observe:

6. Spores just beginning to *germinate*.

[1] Outline is not provided for studying all of the details of reproduction in *Ulothrix* as those details are given in current text-books, since investigations now being made at the University of Chicago indicate that the text-book accounts are in error.

7. Young plants of several cells beginning to assume the characteristics of their parents.
8. The developing "holdfast."

Make drawings illustrating the stages seen in the process of reproduction.

ANNOTATIONS.

In the plant *Ulothrix* we have our first illustration of a filamentous *green* Alga of the family Chlorophyceæ. Its cylindrical cells are placed end to end, and much more firmly united than those of any plant we have yet studied. Furthermore, in most species the basal cell attaches the plant, thereby giving it a degree of permanence of location. In each cell, excepting the "holdfast," we have a well-organized chloroplast in which are special nutritive organs known as *pyrenoids*, which are peculiar to some Algæ. The plants grow in length by having the cells enlarge and divide at right angles to the long axis of the filament. Sometimes plants break, resulting in the production of two or more new individuals.

Asexual reproduction takes place through the formation, by internal division, of specialized bodies known as spores, called zoospores because they move as certain small animals. These zoospores may be formed in the interior of any nutritive cell by the division of its protoplasm, all of which is used in their formation. When the wall of the mother-cell breaks, the zoospores escape and swim about for a time, then come to rest on some support, attach themselves at their ciliated end, and begin to grow into new *Ulothrix* plants. Obviously this zoospore habit

gives the plant advantage over the plants heretofore considered, because it provides for more certain and rapid multiplication and wider distribution.

Sometimes bodies like zoospores, but not true spores at all, since they do not reproduce the kind of plant that formed them, unite, thus forming a spore. When two of these bodies unite (whence called *gametes*) they form a spore which can reproduce the kind of plant that formed them. Such a spore is sexual since it is formed by the union of cells, and this one being formed by the *conjugation* (yoking together) of similar gametes is called a *zygospore* (to yoke; spore). Observe that gametes from widely separate individuals may unite, thus bringing into the sexual spore protoplasm widely separated in origin. It is evident that reproduction by zoospores involves no opportunity of introducing new vigor from a second plant as does reproduction by sexual spores. But it must be kept in mind that sexuality in plants originated from the non-sexual processes of zoospore formation, and that zoospores are the cells that begin to function as gametes. From the condition illustrated by *Ulothrix* there begins a highly important series of differentiations of gametes looking toward the formation of the sexual spore.

CLADOPHORA.

THALLOPHYTES; ALGÆ; CHLOROPHYCEÆ.

PRELIMINARY.

There are many species of this plant, almost any of which will be found suitable for laboratory work. Most of the species grow attached to some support in moving water, while a few may be found floating upon the surface. The plants are much coarser than *Ulothrix* and also much branched, so that they may be distinguished fairly well by the eye alone. They grow well at almost all times of the year. A week or more before the study is to be made some vigorously growing plants should be placed in a dish of water, in a rather dark place, where there is a fairly constant favorable temperature. The water in the dish should be allowed to evaporate slowly. This procedure will often cause some of the cells to produce spores in a favorable condition for study.[1]

[1] If satisfactory material was at hand in the study of *Ulothrix*, the reproduction of *Cladophora* may well be omitted since it is quite similar to that of *Ulothrix*.

LABORATORY WORK.

GROSS STRUCTURE.

1. With some plants in a dish of water compare with *Ulothrix* as to color, coarseness, and position in the water.
2. By lifting some plants from the water on a piece of white paper, determine whether the diameter of a filament is the same throughout.
3. Examine the sides of a dish of plants which has been in the laboratory a week or more to see if any of the germinating spores are beginning to attach themselves to the dish.

MINUTE STRUCTURE.

I. The Plant Body.

Mount one or two plants and under low power observe:

1. The form.
2. The relative size of segments [1] from base to tip.
3. The form of segments at tips of branches as compared with those lower down.
4. The points at which branches arise.
5. Sketch a small plant or part of a large one.

II. The Segment.

Under high power observe:

1. The wall of a single segment of the plant enclosing:
2. The protoplasm, of which (*a*) cytoplasm, (*b*) definitely organized chloroplasts, and (*c*) a few pyrenoids may be distinguished.

[1] In *Cladophora* each apparent cell is really a complex structure within one cellulose wall. Such a segment is said to be a *cœnocyte*. To observe all the points suggested it will be necessary to have specially stained specimens.

3. Whether filaments are furnished with a sheath.
4. How a new branch develops from a cœnocyte.
5. By means of a specially stained specimen locate the numerous nuclei to be found in one cœnocyte.
6. Draw an entire segment and part of one from which a new branch is developing.

III. Reproduction.

1. By use of the low power try to locate cœnocytes in which the protoplasm has divided into a large number of small spores.
2. With high magnification study the form and movement of the spores. By staining with iodin it is sometimes possible to see the cilia by means of which movement occurs.
3. Study some spores which have come to rest on the sides of the dish and note the changes as they are beginning to produce new individual plants.
4. Try to determine whether any of these ciliated bodies unite to form zygospores.
5. Make drawings illustrating the reproduction of *Cladophora.*

ANNOTATIONS.

The vegetative structure of *Cladophora* is more complex than that of any other plant studied. The divisions usually called individual cells are really composed of a wall enveloping what are the essential parts of many cells. The nuclei of the several cells held in the common wall may be seen by means of special stains. These segments are so arranged as to compose a very greatly branched plant, which because of this branching is enabled to expose more chlorophyll to the light. That

Cladophora is well adapted to meet its problems of living is indicated by the almost universal presence of the pl nt wherever there is a constant water-supply. By means of its strong "holdfast" it is enabled to grow in running water and on wave-beaten rocks, in which places it frequently forms very luxuriant growths.

In reproduction *Cladophora* bears close resemblance to *Ulothrix.*

COMMON POND-SCUM.

Spirogyra.

THALLOPHYTES; ALGÆ; CHLOROPHYCEÆ.

PRELIMINARY.

THE members of this genus are abundant in stagnant water everywhere, forming bright yellow-green scums of great extent, sometime diffused beneath the surface, or occasionally in running water attached to stones. They may be distinguished readily from all other scum-producing plants, except from a few of their close allies, in having a slippery feel, and being composed of long unbranched filaments, which string out like wet hair when withdrawn from the water. The allied kinds, which cannot be separated by this test, will at once be distinguished when placed under the microscope by possessing no spiral chlorophyll bands as does *Spirogyra*. When growing vigorously the masses of *Spirogyra* are an intense light green; when beginning to form spores they turn yellowish, and look very uninviting; but as the characteristics which distinguish the species are largely drawn from the reproductive condition, the collector soon learns to regard these unsightly objects with favor.

The vegetative condition may be found at any time during the warmer portion of the year. The reproductive condition occurs from early spring to June and July, and sparingly during the remainder of the warm season. The species usually grow intermixed, and almost any species gathered will answer for the present study, though one with a small number of loose spirals is best.

LABORATORY WORK.

GROSS STRUCTURE.

Taking fresh specimens in a white dish, observe:

1. The vivid but yellow-green color as seen in the mass.
2. The slippery feel when the plant is taken between the fingers.
3. The fine unbranched filaments of which it is composed.
4. The uniform diameter.
5. Their length.

Place some in alcohol and after some time notice:

6. The color imparted to the alcohol by the chlorophyll.

MINUTE STRUCTURES.

I. Vegetative Characters.

Under low power observe:

1. The length; if traced to the end, the filament will probably be found broken.
2. The uniform diameter.
3. The cell contents; colorless, except the conspicuous green chlorophyll bands.

Using a high power observe:

1. The shape of the cells.
2. Their relative length and breadth.

3. The cell wall:
   a. The lateral walls; parallel and without markings of any sort.
   b. The end walls; at right angles to the longitudinal axis, and plane (unless slightly nodulated or infolded, which occurs in a few species).
4. The absence of any visible sheath, although the presence of at least a thin one has been demonstrated by the slippery feel.
5. The cell contents:
   a. The chlorophyll bands (chloroplasts), taking a spiral course from one end of the cell to the other, passing near the periphery. Note:
      (1) The number in each cell.[1]
      (2) The number of turns of the spiral.
      (3) The surface, the crenulated and wrinkled margin, and the turned-up edges of the band forming a more or less flattened V in optical section. To obtain a complete conception of these particulars, first focus upon the peripheral surface of the band, i.e. upon the upper (outer) surface of the part nearest the eye, then focus upon the axial (inner) surface, and finally examine the profile of the band seen on the right or left of the cell.
      (4) The nodules at varying distances along the median line of the band. Stain with iodin, and in the nodule note:
         (*a*) An outer ring of granular material which is more deeply colored, the starch grains,[2] and
         (*b*) A central light spot, *pyrenoid*. Both are best seen when but faintly colored.

[1] If crowded so as to make a direct count difficult, see Bot. Gaz. 9: 13, for an easy method of determining the number.

[2] Unless the plants have been in sunlight for a few hours the test for starch may not be fully successful.

(5) The yellowish-brown color finally imparted to the chlorophyll band.

b. The feeble brownish color given to the remainder of the contents of the cells, deeper along the periphery.

c. In cells presenting the least obstruction from the chlorophyll bands, search for a colorless oval or spindle-shaped body, the *nucleus*,[1] imbedded near the center of the cell in a mass of protoplasm with arms radiating to the peripheral protoplasm. The peculiar conditions found here would at first glance lead one to suppose the real nucleus to be a nucleolus.

II. Reproductive Characters.

Mount filaments thought to be in reproductive stage, and under low power search for:

1. Filaments lying side by side in pairs, held together by transverse branches, the *conjugating tubes*.
2. Some filaments having an irregular outline, caused by uneven lateral expansions, the beginning of conjugating tubes. When conjugating filaments are found, observe:
3. The varying character of the contents of the cells: some with spiral bands of chlorophyll; some with a confused green mass; some with green or brown oval bodies, the *zygospores;* some empty.

Under high power observe:

4. The conjugating tube connecting two cells:
   a. The enlargement at the middle, where an indentation marks the line of union of the two originally separate branches.
   b. What variations in directions of the conjugating tubes can be found?

[1] This is not easily demonstrated in all species, although the iodin usually stains it a light brownish color.

c. Search for various stages in the growth of the conjugating tubes, and observe whether tubes from conjugating cells always begin in pairs; also whether one cell ever conjugates with more than one other cell.

5. The cell contents.
   a. By studying various specimens, trace the changes from the vegetative condition through the several stages of disintegration of the chlorophyll band and contraction of the protoplasm to the formation of a rounded greenish-brown mass; noticing at the same time that this change is contemporaneous with the formation of the conjugating tube. Usually all stages are easily found.
   b. Where the conjugating tube is fully formed, note that one cell is empty, and the connected cell contains a single mass, the spore produced by the conjugation.
   c. When the cells of two filaments have conjugated see whether all the zygospores formed lie in the cells of one filament of the pair.
6. The mature zygospore. Note:
   a. Shape and color.
   b. Contents.
   c. The wall of greater or less thickness, usually resolvable into two or more layers of different colors.
7. Make drawings to illustrate the parts and changes of the reproductive filaments.

ANNOTATIONS.

In form and manner of growth *Spirogyra* shows no essential features not seen in plants already studied, except the arrangement of the protoplasm and chlorophyll bodies. The filaments are built on the plan of *Oscillatoria* and *Ulothrix*, with the cells larger, and the sheath so much reduced that it can be demonstrated only with

difficulty. In some species of the closely related genus *Zygnema*, however, the sheath is readily discernible. The increase in the number of cells is effected in the same manner as in the other filamentous plants, i.e. by the division of the cell into halves by a transverse partition always in the same plane, with subsequent expansion of the new cells.

The distribution of the protoplasm here as in *Cladophora* and *Ulothrix* shows a marked advancement over the lower plants. Instead of being diffused evenly through the cell, it forms a layer lining the cell-wall, while it only partly occupies the central portion of the cell. The remaining space is filled by the cell-sap, which consists of water holding various substances in solution. Within the central part of this sap region is the nucleus suspended by means of cytoplasmic threads from the peripheral protoplasm. In the form of the chloroplast band we have a striking feature; for although it is common to have the chlorophyll held in well-defined bodies, it is only in *Spirogyra* and its close relatives that they assume such peculiar and beautiful shapes.

The presence of starch granules in the chlorophyll bodies is a very significant fact physiologically. Starch-like substances, which afterwards may be made into starch, are among the first products that chemists have been able to determine in the processes of making food material by plants.[1]

The starch is imbedded in the chloroplasts, and is quite distinct from the pyrenoid, although the constancy

[1] Read on "Photosynthesis" and "Construction of Foods by Green Plants," sometimes called assimilation in various texts at hand.

in the relative position of the two would indicate some connecting influence. The pyrenoids have been long known and variously interpreted, but recent careful studies show that their outer parts are converted bodily into starch. Their chemical constitution is uncertain, though they respond to tests for proteids. Their occurrence is not common throughout the plant kingdom.

When we examine the reproduction of *Spirogyra*, we find that in its details it is quite unlike any plant yet studied. In it we have the sexual process much more developed than in *Ulothrix*, inasmuch as the sex-cells, or gametes, do not become free-swimming bodies, but by means of a conjugating tube one travels directly to the other and unites with it to form a spore.

That these fusing cells are not always of the same size is sometimes quite clear, and it has often been pointed out that they are sometimes unlike, but they are so essentially similar that they can hardly be distinguished as male and female elements in spore formation. Hence the reproduction is said to be *isogamous*, i.e. by similar gametes.

The zygospore formed thus, after developing a heavy protecting wall, may pass through a long period of rest, and then by germination may develop a new plant. Evidently, therefore, *Spirogyra* is not only a larger and more complex plant, and thereby able to do more work, but has developed the special device of a well-protected spore which is adapted to carrying the plant through drouth and winter. Since these spores are dense and have a heavy wall they sink to the bottom of the water as soon as they are set free by the partial decay of the

walls of the filament in which they were formed. Although formed in the earlier part of the warm season, usually they will not germinate at once, but remain dormant in the mud at the bottom of the pool or stream until the next spring, when they form new plants.

VAUCHERIA SESSILIS.

THALLOPHYTES; ALGÆ; CHLOROPHYCEÆ.

PRELIMINARY.

THIS species of *Vaucheria* is quite common on the damp earth and pots of greenhouses, and may often be found out of doors in damp shady places. Other species may also be found in similar places as well as in quiet pools of water. The members of the genus may usually be distinguished by their coarseness, the filament often being large enough to be seen singly with the unaided eye. When growing upon damp earth the slightly brownish-green color and the felt-like appearance make it rather easy to distinguish this plant from other Algæ. Material in the reproductive stage is not always found easily in nature, and when found should be preserved. It may be obtained by placing some of the vegetative plants in a dish of water and putting them where they will be well lighted. In this way zoospores and sexual spores may usually be obtained in from five to ten days. This treatment also produces new growth favorable for a study of vegetative structures.

LABORATORY WORK.

GROSS STRUCTURE.

1. Study the general appearance of the mat of plants as they rest on earth or in water.
2. Note whether they are entirely outside the earth.
3. Note whether the growing tips have any definite position relative to the light.

Float out some of the plants in a watch-glass, and by use of the hand-lens note:

4. Branching of plant body.
5. Whether any small dark bodies—*oogonia* in which oospores are found—can be seen at the sides of plants. Even when present they cannot always be seen with the hand-lens.
6. Whether there are large, free, green, swimming spores, the zoospores.

MINUTE STRUCTURE.

I. VEGETATIVE CHARACTERS.

Carefully remove the earth from a few plants and mount. With either low or high power, as the case may require, observe:

1. The length, diameter, and branching.
2. Absence of cross cell-walls separating the protoplasm into the ordinary cells. It is a cœnocyte. Examine specially stained specimens.
3. Position, form, and abundance of chloroplasts.
4. Parts of some plants which have no chloroplasts. Account for their absence.
5. The method of formation of new chloroplasts, as shown within actively growing plant-tips.
6. Make drawing illustrating the structure of the plant body.

II. Reproductive Characters.

1. Asexual reproduction.

At the tips of some branches search for the following stages:

a. Where there has been formed a transverse partition-wall.

b. Where the protoplasm thus enclosed is becoming spherical in form.

c. Where this large mass of protoplasm, which is a compound zoospore, is escaping from its enclosing walls.

d. Search for free zoospores and observe the movements.

Around the margin of the dish, or held by the older plants if the material has been kept for a few days, may be found specimens which when mounted will show:

e. Young plants beginning to grow from zoospores.

f. Draw.

2. Sexual Reproduction.

On the side of filaments may frequently be seen some branches of one or two kinds, as follows:

a. The oogonium, an oval body with a beak-like tip, containing an *oosphere*, the female gamete, or sex spore, the *oospore*.

b. Arising from the filament near the base of the oogonium is the *antheridium*,[1] an elongated and coiled body.

c. Note how the structures are adapted to aid in the union of the passive egg of the oogonium and the motile sperm from the antheridium.

d. Observe the very heavy wall about the oospore or fertilized egg. Of what significance is this?

e. Draw oogonia, antheridia, and oospores.

[1] In *V. sessilis* the antheridial stalk arises as a separate branch from the plant body, while in other species, e.g. *V. geminata*, the antheridial stalk is the termination of a branch on the side of which one or more oogonia may be borne.

ANNOTATIONS.

We have in *Vaucheria* a green Alga which is, in some ways, quite peculiar. It has a cœnocytic plant body; it is relatively rather large, and produces massive zoospores which are covered with cilia and are of immense size when compared with other zoospores. These are called compound zoospores, and are supposed to represent many small zoospores, each pair of cilia protruding through a thin peripheral sheath corresponding to the pair of a simple zoospore. Furthermore, the plants of this genus have a distinct tendency to frequent damp earth rather than to live in the water.

As a form illustrating the line of evolution of sexual reproduction in the Algæ *Vaucheria* is quite significant. Here the gametes are not similar, as in *Ulothrix* and *Spirogyra*, one having become large and inactive, while the other is small and active. This differentiation is indicated by using the term female gamete, or *egg*, for the larger gamete, and male gamete, or *sperm* or *antherozoid*, for the smaller one. The larger size of the oospore, produced by union of the sperm with the egg, makes possible the storage of greater amounts of food material for the nourishment of the new plant when it germinates. Fertilization is accomplished by the active swimming of the sperm to the egg and fusing with it. Since the number of sperms is very much greater than the number of eggs, the chances of fertilization are thereby greatly increased.

It is to be noted further that ordinary vegetative cells do not produce either zoospores or gametes. In the

case of zoospores the end of a nutritive filament is made into a sporangium, which produces one large compound zoospore, while special branches and sex-organs are developed to produce the sex-cells. The oogonium that produces the egg, and the antheridium that produces the sperms, are not only special organs for production of these special bodies, but by their structure, and their position with reference to each other, greatly facilitate the process of fertilization. The division of labor between nutritive and reproductive organs is well established. Furthermore, the oospores are protected by heavy walls as in *Spirogyra*, which gives greater chances of successfully surviving severe changes in temperature, moisture, etc. It is evident that *Vaucheria* shows a decided advance in complexity.

COLEOCHÆTE.

THALLOPHYTES; ALGÆ; CHLOROPHYCEÆ.

PRELIMINARY.

THIS plant grows in standing water, and is seen as small green disks on sticks, stones, etc., in quiet water. The plants are quite small and are not easily recognized.[1] When material is found it may be brought into the laboratory on its supporting substance, and may be preserved thus. Since the form is rather rare, permanent mounts should be made when good material is found.

LABORATORY WORK.

GROSS STRUCTURE.

1. The size and general distribution of plants upon the substratum.
2. Color.
3. Form. Are any branches at margin of disk discernible?

[1] In many localities *Coleochæte* is not abundant, but because of its great importance in the chain of forms which illustrate the evolution of plants it is introduced, and fresh or preserved specimens should be obtained. If material cannot be had, the form should be carefully studied from text and manual.

MINUTE STRUCTURE.

I. Vegetative Characters.

Remove and mount some of the plants, and by use of the low power observe:

1. The form and arrangement of cells composing the plant.
2. The number of cells in thickness.
3. Whether the plant is a compact disk.

By using the high power examine:

4. The details of cell-structure and arrangement.

Outline an entire plant and draw in detail a sector of the plant from the center of the disk to the margin.

II. Reproductive Characters.

5. Observe cases where the disks may be dividing to form new ones vegetatively.

At the tips of branches at the edge of the disk the sex-organs arise. Note the reproductive structures as follows:

6. Oogonium, a somewhat elongated cell narrowed abruptly into a long tubular projection (*trichogyne*); observe the egg within the oogonium.
7. The antheridia, small cells formed on the marginal ends of filaments. Observe whether in those seen any sperms are being formed.[1]
8. After the egg is fertilized the base of the oogonium becomes encased, and after a period of rest the oospore rearranges its contents to form a number of zoospores that escape and grow into new *Coleochæte* plants. Try to find some of these stages.[2]

Make drawings illustrating reproductive structures of *Coleochæte*.

[1] If good prepared slides are available, they will be found advantageous in the study of 6, 7, and 8.

[2] For a good statement and illustration of the details of reproduction in *Coleochæte* see "Die Entwickelung der Sexualeorgane bei *Coleochæte pulvinata*," by E. Oltmanns. Flora, **85**: 1–17, 1898.

ANNOTATIONS.

This plant is one of the most complex of all Chlorophyceæ. The plant body is not filamentous as in others, but the cells divide in two planes and remain closely joined, laterally as well as endwise, thus forming a flattened plate of cells one layer in thickness. Although each cell of the plant usually contains chlorophyll, it is evident that the lower side will tend to absorb most materials from the substratum, while the upper side is best placed for chlorophyll work; consequently we have something like a division of labor between the dorsal and ventral sides, though the plant is but one layer of cells in thickness.

Of the sex-organs the oogonium is more complex than any seen before in that it has a long hair-like extension from the bulbous base. This oogonium is not unlike what we should have if the open end of the *Vaucheria* oogonium should become narrow and long. The antheridia are small specialized cells formed on the tips of marginal cells, which were originally nutritive. In this respect the plant is less advanced than *Vaucheria* and resembles *Spirogyra*, all of whose reproductive cells are for a time nutritive.

After fertilization the egg does not grow at once into a new plant, but becomes encased by cells that grow up around it, and passes through a resting period. After the resting period the protoplasm of the oospore divides, forming a number of zoospores (usually eight), each of which can form a new *Coleochæte* plant. Evidently, therefore, we have a sort of alternation, since the

oospores form zoospores, and from the zoospores there develop plants which after a period of growth can develop oospores again.[1]

[1] It will be profitable at this stage to compare nutritive structures and the methods of reproduction in *Ulothrix*, *Spirogyra*, *Cladophora*, *Vaucheria*, and *Coleochæte* with similar structures and processes in the red Algæ (Rhodophyceæ) and in the brown Algæ (Phæophyceæ). In addition to laboratory work, the following references suggest sources of information in addition to the text descriptions, which all should read:

(*a*) Davis, B. M. Development of the cystocarp in *Champia parvula*. Bot. Gaz. **21**: 109–117, 1896.

(*b*) —— Fertilization in *Batrachospermum*. Ann. Bot. **10**: 49–76, 1896.

(*c*) Farmer, J. B., and Williams, J. L. Contributions to our knowledge of the Fucaceæ. Phil. Trans. Royal Soc. London. Ser. B. **190**: 623–645, 1898.

(*d*) Chester, Grace D. Notes concerning the development of *Nemalion multifidum*. Bot. Gaz. **21**: 340–347, 1896.

COMMON BLACK MOLD.

Mucor stolonifer (*Rhizopus nigricans*).

THALLOPHYTES; FUNGI; PHYCOMYCETES.

PRELIMINARY.

The molds are quite common, appearing on stale bread, damp leather, and decaying fruits, sometimes as grayish fluffy masses and sometimes as blue or yellow coatings to their substrata. *Mucor* may usually be grown quite readily upon a sweet potato or a piece of moist bread kept at favorable temperature in a closed glass dish or under a glass bell.

Although it is an easy matter to obtain molds which reproduce themselves by asexual spores, it is usually quite difficult to induce them to undertake sexual processes. It is supposed that *Mucor* plants have almost discontinued reproduction by means of sexual spores. However, zygospores may sometimes be obtained by growing the material under a glass cover, keeping it moist, and not in direct sunlight, and maintaining a constantly favorable temperature of 22° to 25° C.[1]

[1] In a brief article on "Sexual Reproduction in the Mucorineæ" by A. F. Blakeslee in Science, 19: 864, 1904, and an extended discussion

LABORATORY WORK.

GROSS STRUCTURE.

The vegetative body of the plant consists of a network of branches (*mycelium*) upon and within the material which furnishes food, and upright branches from the mycelium. A separate branch (*hypha*) may pass through the substratum and then emerge upon its surface as an aerial stalk. Observe:

1. The general appearance of the entire mass of plants.
2. The different positions of the threads with reference to the supporting substance.
3. Certain hyphæ which arise from the mycelium and again come in contact with the substratum, branching at the place of contact, and thus extend the plant.
4. The aerial hyphæ (sporangiophores) upon which the black tips (sporangia) have formed.

MINUTE STRUCTURE.

I. Nutritive Structures.

Carefully remove a small amount of the material from its substratum, mount and study, observing:

1. The network of hyphæ composing the mycelium.
2. The branching of hyphæ.
3. Absence of walls separating individual cells; therefore it is a cœnocyte.

of the same subject by the same author in the Proc. Am. Acad. of Arts and Sciences, **40**: 205–319, 1904, it is concluded that zygospore formation in the Mucorineæ "is conditioned by the inherent nature of the individual species and only secondarily or not at all by external factors." It is further concluded that there are two races of *Rhizopus nigricans* (*Mucor stolonifer*), as well as of other Mucorineæ. One race is monœcious, the other diœcious. In order to obtain zygospores from the diœcious race it is necessary to have both positive and negative strains growing together.

4. From the lower ends of some hyphæ the root-like branches (*rhizoids*) which penetrate the food material.
5. The granular protoplasm, in some places densely filling the hyphæ.
6. Draw.

II. Reproductive Structures. Observe:

1. The sporangia, in which are blackish masses of spores.
2. Stages in the development of sporangia, showing:
   a. The tip of an aerial hypha beginning to become swollen.[1]
   b. This swollen tip separated from the hypha by means of a transverse wall.
   c. Young sporangia containing immature masses of spores, grayish in color.
   d. Mature sporangia with ripe masses of spores.
   e. The broken sporangium, the swollen tip of the sporangiophore (*columella*), now bulged up into the sporangium, and the free spores.
3 Draw.
4. Make a rough estimate of the number of spores in a sporangium, and count the number of sporangia in one mount.

With material that is known to show sex-organs [2] observe:

5. Branches that have their tips greatly enlarged and growing toward one another.
6. Such branches whose ends have become cut off by transverse walls, and are in contact.
7. The process of union (*conjugation*) of these end cells.

[1] Care must be taken not to mistake the swollen columella (see *e*) which supported an old sporangium, for early stages in the development of a young sporangium. A columella usually bears a scar which shows where the old sporangium wall was attached.

[2] Unless there is assurance that the material will show sexual reproduction, no time should be consumed with this part of the study. See text-books for descriptions.

8. Completed zygospores as the result of conjugation of the end cells.
9. Draw.

ANNOTATIONS.

Fungi are devoid of chlorophyll and consequently cannot utilize sunlight and inorganic substances in initiating the process of food construction. All Fungi must obtain food at least partially prepared for them. *Mucor* may obtain its nourishment from a variety of dead organic bodies. Its spores are so abundant that the plant usually appears when favorable conditions of growth are provided.

The branching cœnocytic body of *Mucor* is quite like some of the Chlorophyceæ among the Algæ. The sexual reproduction recalls strongly the formation of zygospores in *Spirogyra* and its nearest relatives among the green Algæ, and this is taken to indicate a possible close relationship between these groups, it being supposed that *Mucor*, as well as some other Fungi yet to be considered, have descended from like ancestors with such Algæ as *Spirogyra* and *Vaucheria*. The gradual adaptation to a dependent habit of living was doubtless accompanied by the gradual loss of chlorophyll, so that the plants now bear little superficial similarity to Algæ, and only a more detailed study of the structures that are least likely to be affected by such habits reveals the relationship.

The wide distribution of the molds and the readiness with which they grow on decaying substances must be recognized as of considerable economic significance. As agencies of decay, they not only prove injurious to some substances, but are helpful in reducing many others to a form again usable by other plant life.

TOADSTOOL OR MUSHROOM.

THALLOPHYTES; FUNGI; BASIDIOMYCETES.

PRELIMINARY.

IN making this study almost any common species of the group will serve as a type. The outline is prepared with especial reference to the ordinary species of the genera *Agaricus* and *Coprinus*. The plants may be found readily in rich earth in warm, wet weather, or immediately following a warm rain. Those forms which grow from the ground rather than those upon trees, stumps, etc., will usually answer best for laboratory work, though representatives from different substrata should be examined. All stages, from those just emerging from the ground to those quite old, should be obtained for laboratory study; also some of the material on which the plants are growing.

LABORATORY WORK.

GROSS STRUCTURE.

Examine a fully formed "toadstool"; also one in which the top is not yet easily distinguished from the stalk, and observe:

1. The stalk or *stipe*.
2. The expanded top, the *pileus*, on the under side of which are:

3. The *gills*.
4. At the base of the stalk are usually some fragments of the mycelium from which the "toadstool" grew.
5. Divide a "toadstool" lengthwise, and observe the inner structure.
6. Dissect very young and older specimens, and observe:
   a. The *gill-chambers*, the floor of which becomes thinner with age, and forms:
   b. The *veil*, ruptured as the pileus expands.
   c. The *ring*, a scar-like remnant of the union of veil and stalk.
7. Make drawings illustrating the structures seen.

MINUTE STRUCTURE.

1. Dissect carefully a piece of the stalk and observe the arrangement of hyphæ which compose it. Draw.

With dissected material from the gill or preferably with especially prepared sections that were cut transverse to the flat surface of the gill,[1] study its structure. Observe:

a. A loosely interwoven mass of hyphæ in its middle, and a denser mass at the surface. What position do the ends of hyphæ have?
b. The *basidia*, club-like ends of hyphæ, which arise from the denser surface of the gill.
c. *Paraphyses*, the sterile filaments parallel to the *basidia*.
d. The spores, a definite number formed upon each basidium, each spore arising from
e. A *sterigma*, a short horn-like process.
f. Draw.

[1] Care must be taken to obtain proper material for such sections. If it is too old, the spores will be gone from the basidia, and if too young, they cannot be readily demonstrated.

ANNOTATIONS.

The *Basidiomycetes*, to which the toadstools, mushrooms, and puffballs belong, are probably the most conspicuous representatives of the Fungi. Some of the forms are saprophytic and others are parasitic in their way of living. It is customary in the entire group to have most of the mycelium growing within the substance which furnishes food, and to have the organs for spore formation developed aerially. The main body of the structure ordinarily called the toadstool is made up of a mass of hyphal threads. Some of these threads pass through the stalk and into the gills, and terminate in club-like expansions which extend outward from the surface of the gill. From these club-like expansions, the basidia, there arise small tapering branches whose tips gradually enlarge until a spherical body is formed, which finally becomes a spore. In some species four and in others two such spores are formed. To indicate the peculiar way in which it is formed this is called a *basidiospore*. The spores are usually distributed by the wind, though a variety of agencies may be used. They germinate, and if in favorable location develop a new mycelium and eventually a new toadstool.[1]

[1] Examine texts to discover the prevailing opinions regarding homologies between the basidium and the sporangium.

ALBUGO PORTULACÆ OR A. CANDIDA.

THALLOPHYTES; FUNGI; PHYCOMYCETES.

PRELIMINARY.

THESE are very common parasitic Fungi. *A. candida* forms white patches on the surface of the leaves, stems, and flowers of many cruciferous plants, such as various species of *Capsella*, *Sisymbrium*, *Lepidium*, *Nasturtium*, *Sinapis*, and *Raphanus*. It is especially abundant upon *Capsella*, or "shepherd's-purse," from early spring until late in the fall, whitening and distorting the stems, leaves, and flowers. Yet, notwithstanding its luxuriant growth, the sexual condition with resting spores is not abundant within the tissues of this plant, but is produced in great luxuriance inside the flowers and flowering branches of radish (*Raphanus*), causing them to become enormously enlarged, sometimes becoming even two to five centimeters (one or two inches) across.

A. Portulacæ, found upon the leaves of purslane or "pusley" (*Portulaca oleracea*), serves equally well for this study, sex-organs being much more readily found in it than in *A. candida*. *A. Bliti* is very common on the leaves of the common pigweed (*Amarantus retroflexus*).

It is possible, with patience and care, to make out the parts without the use of special stains, but these afford so much assistance that they should be used if possible.[1]

LABORATORY WORK.

GROSS STRUCTURE.

The vegetative body of the plant consists of delicate transparent threads, ramifying through the tissues of the host on which it grows, and cannot be detected without the aid of the compound microscope. In a fresh or dried specimen, observe:

1. The white blister-like pustules on the surface of the host, the *sori;* their form. Observe the distortion and enlargement of the stems and leaves where the blisters (sori) are.
2. The thin external membrane, at first entire, then becoming ruptured in the midde.
3. The white powdery spores, *conidiospores*, which drop out upon jarring, if the specimen is dry.

MINUTE STRUCTURE.

I. Asexual Reproduction.

Mount a transverse section of a fresh or preserved specimen of a stem or leaf bearing *Albugo,* and under low power observe:

1. A layer of short vertical filaments, *conidiophores*, which appear to rise from the tissues of the host and bear on their free extremities:
2. Chains of rounded spores (*conidia*), now mostly detached.
3. The ruptured membrane consisting of the surface-cells of the host, formerly covering the sorus.
4. Draw.

The vegetative portion of the plant, consisting of branching filaments pervading the tissues of the host, if studied by

[1] For directions for staining Fungi see Chamberlain's "Methods in Plant Histology," p. 79.

means of sections, requires excellent staining before it can be distinguished. If the material be boiled for one minute in a five per cent solution of potassium hydrate, the tissues may be teased apart with needles and the mycelium exposed. Under high power, with a good dissection or a well-stained section, observe:

5. The conidia; exact shape, wall, and contents.
6. The delicate neck or pedicel supporting each conidiospore before becoming detached.
7. Draw a conidiophore with its conidiospores.

Trace a conidiophore into the tissues of the host plant,[1] and observe:

8. The irregular thickness of the hyphæ.
9. Whether it branches.
10. Whether partition-walls are present.
11. The way in which the hyphæ apply themselves to the host cells. The specialized organs, the *haustoria*, by means of which the parasite obtains food from the host cells, are found more readily in the tissues of growing tips and flowers.
12. Draw, showing hyphæ and host cells.

Dust some conidiospores from a fresh growing plant[2] upon a slide and mount with water;[3] in about an hour observe:

13. The small protuberance formed on one side of some of the conidiospores which opens and permits the escape of the protoplasm in the form of several motile bodies, *zoospores*.

[1] This is not always possible, since the hyphæ pass in various directions and many are cut off in making the section. The circular cut ends may easily be seen.

[2] The conidia will germinate if sown at any time of day, provided the specimens are fresh, but will do so more readily when sown in the morning from plants which have remained over night under a moist bell-jar.

[3] Care must be taken that the water does not evaporate, and to guard against this it is best to keep the slide in a moist chamber.

a. The shape of the zoospores, and the pair of bright spots in each.

b. Study the movement.

c. Notice the pair of delicate vibratile cilia, by means of which the movements are effected. Stain with iodin and the cilia can be seen more easily. Note their length.

d. The color imparted to the zoospores and their cilia by the iodin.

e. Draw some zoospores, and also one or two conidia which have not discharged zoospores, and one or two empty ones.

II. SEXUAL REPRODUCTION.

With a dissection or a properly stained section of a specimen containing oospores, observe:

1. The numerous globular bodies, distinct from and lying in the cells of the host, the oogonia.
2. Accompanying them, and stained the same color, smaller rounded or elongated bodies, the antheridia.
3. The way in which the oogonia and antheridia arise from the hyphæ.
4. In some of the oogonia, a globular mass of granular protoplasm, not completely filling the oogonium, the oosphere.
5. A slender tube passing from the antheridium to the oosphere, the *fertilizing tube:* usually difficult to demon-monstrate.[1] Draw.
6. The development of oospores from oospheres as shown by the various stages in which they have been killed.

[1] It has been shown that the fertilizing tube brings nuclei into the oogonium and that these unite with a corresponding number of nuclei within the oospore. See figures in articles by F. L. Stevens on "The Compound Oospore of Albugo Bliti," Bot. Gaz. **28**: 149 and 225; also "Gametogenesis and Fertilization in Albugo," Bot. Gaz. **32**: 77, 157, and 238.

7. In older oogonia, more opaque bodies, the oospores formed from the oospheres. Observe:
   a. Their irregular ridges on the external wall of mature oospores.
   b. The contents, in younger spores.
8. Draw some oogonia and the accompanying antheridia showing different stages of development of the oospheres and oospores.

ANNOTATIONS.

In *Albugo* we have a plant in some respects simple, and in some quite complex. The higher development is shown in its sexual elements being quite dissimilar in size and behavior. The larger female organ, the oogonium, receives the protoplasm of the smaller male organ, the antheridium, the former remaining in a passive state, while the antheridium is the active agent in securing the union. This is the essential plan for all higher plants, as well as for some Algæ, as has been seen in previous work. The transfer of the protoplasm by means of a fertilizing tube, and the subsequent formation of a thick-walled resting spore, bears a striking resemblance to what takes place in *Spirogyra* and *Vaucheria*. In both cases the spore clothes itself with a wall which differentiates into a delicate inner layer and an outer, thick, protective one. In *Albugo* this outer wall is marked in a manner characteristic of the species. The oospores thus formed remain over winter, until the tissues in which they lie become disintegrated, when they are distributed by rain and wind, and finally germinate.

Next to the mode of sexual reproduction the most

interesting feature of the plant is its habit of life and the adaptations which have been induced thereby. It is throughout its existence a complete parasite, growing and feeding upon plants of very high organization. Being no longer required to elaborate food for itself, finding it always at hand and of superior quality, it possesses no chlorophyll bodies by which it might construct its own food, and is therefore quite colorless. As it grows it sends its branches throughout all the softer tissues of the host. They do not penetrate the cells directly, however, but push about between them, and in order to extract the food readily, especially in the newest portions where rapid growth is taking place and food is therefore abundant, send out slender haustoria which penetrate the adjacent cells and expand into minute absorbing bulbs.

The means of distribution which the plant possesses in its oospores is rather limited, being inferior to that of *Spirogyra* and *Vaucheria;* and when once established in a host it is debarred from all further locomotion, such as the moving water imparts to the spores of some other plants. In order to secure certain and extensive distribution, therefore, and to provide for a succession of crops through the growing season, it produces conidiospores or summer spores in the greatest profusion, which being light and dry are easily blown about by the wind, and are ready to germinate at once. The thin wall and active protoplasm of the conidia, from which they derive this advantage, render them at the same time short-lived, so that if a conidiospore does not find favorable conditions for growth within a few hours after reaching maturity it perishes. The conidia germinate in water,

and with best results in a film of water, such as is formed by heavy dew. To promote distribution still further, each conidium often breaks up into several active zoospores, which, after moving about for fifteen minutes or so, finally come to rest, put out a mycelial tube that penetrates the host, and form a new plant. The zoospores, except in being colorless like the parent, remind one of those of *Ulothrix*, serving the same purposes of distribution and reproduction.

The absence of septa, except for the separation of the antheridia, oogonia, and conidiospores, making the vegetative portion a continuous cavity, is a character shared with *Cladophora*, *Vaucheria*, and *Mucor*, as well as many other forms, both green and non-green.

THE LILAC MILDEW.

Microsphæra alni or *M. quercina.*

THALLOPHYTES; FUNGI; ASCOMYCETES.

PRELIMINARY.

The lilac mildew, *Microsphæra alni*, is extremely common in the United States, making the upper surface of the leaves look white and moldy from midsummer on. *M. quercina* is quite common upon oak-leaves and is equally favorable for study. The first stage at which the Fungus is ready to gather is when it appears powdery, which is usually in June or July, the earlier collections being the best. The next gathering should be made in the early part of September, and another just before the leaves fall. As the leaves bearing the Fungus are gathered, lay them in a book or plant-press to dry. If it is possible to examine the first stage with fresh material, it will prove more satisfactory, but for the remainder dried material will answer quite as well. Specimens of the first and second collections preserved in alcohol or formalin will often prove helpful in the work.

LABORATORY WORK.

GROSS STRUCTURE.

I. General Characters. Observe.

1. The distribution of the Fungus on the surface of the leaf.
2. The color.

II. The Conidiospores. Observe:

1. The pulverulent appearance on the leaves first gathered, caused by the abundant conidiospores.

III. The Fruit. Observe:

1. The black dots on the leaves gathered later in the season, the *spore-fruits*, or *ascocarps*.
2. Associated with the black dots, other yellow ones, the immature *ascocarps*.

MINUTE STRUCTURE.

I. The Mycelium.

Scrape the Fungus from the surface of a leaf gathered in early summer. First moisten it with dilute potassic hydrate if the specimen is a dried one, and under high power observe:

1. The colorless filaments of the mycelium.
   a. The branching.
   b. The irregular diameter.
   c. The rarity of partition-walls.
2. Small lateral expansions of the filaments, haustoria, somewhat like irregularly indented disks with very short thick stalks, generally difficult to find.
3. Draw.

II. Conidiospores.

Prepare a slide as before from a pulverulent surface, and observe:

1. The abundant conidiospores, separated and free, owing to the manipulation.
   a. Their shape and color.
   b. The cell-wall and contents.
2. The branches bearing conidiospores (the conidiophores) which leave the mycelial filaments at right angles, and are provided with cross-partitions at regular intervals, and may yet have some fully formed spores attached.
3. Draw some spores, a conidiophore, and the hypha from which it arises.

III. THE ASCOCARPS.

Prepare a slide as before, but from mature material, and examine the ascocarps, observing:

1. The shape and color.
2. The reticulations of the surface.
3. The *appendages* extending out from the sides. Observe:
   a. The number.
   b. The color.
   c. The length compared with the diameter of the ascocarps.
   d. The cross-partitions, if any.
   e. The manner of branching, and the number of divisions in each.
4. Draw an ascocarp with its appendages. By pressing on the cover-glass with a scalpel-handle or dissecting-needle, crush the ascocarps while watching them through the microscope, and observe:
5. The escape of sacs (*asci*) containing spores. Observe:
   a. The number from each ascocarp.
   b. The general shape.
   c. The short pedicel or beak by which they were attached.
   d. The thin part of the wall at the apex, not to be seen in every case.

e. The number of spores (*ascospores*) in each; their shape; their arrangement.

f. Draw an ascus with its spores.

6. Examine younger and younger ascocarps to as early a stage as can be found. Draw.

IV. THE SEX-ORGANS.

The very simple sex-organs are not easily found;[1] if seen, observe:

1. The larger axial cell, the *carpogonium*, homologous with oogonium.
2. The smaller lateral cell, applied closely to the carpogonium, the antheridium.
3. Draw.

ANNOTATIONS.

The group of plants to which *Microsphæra* belongs, a very large one, is characterized by having a special covering for the spores, known as the ascus. This is developed probably as a result of fertilization. Except in some of the higher forms, fertilization takes place much as in many other plants, but the subsequent development is very different, for an outgrowth of the plant from the portion immediately below the organs of fertilization at once arises which eventually envelops the forming spores and develops into the body of the ascocarp.

It is quite possible that *Microsphæra* has reached an advanced parthenogenetic stage, i.e. the "fruits" may

[1] In most material it will not be possible to find these organs. To get a good notion of them examine the cuts illustrating ascomycete reproduction in the text-books; also in a special article by R. A. Harper, on sexual reproduction in *Pyronema confluens*, and the morphology of the ascocarp; in Ann. of Bot. 14: 1900. (This paper contains a good bibliography of the entire subject.)

be largely produced without the transfer of protoplasm from the antheridium to the carpogonium, which constitutes fertilization. On this account some other plants better illustrate the fertilization and the early growth of the "fruits" than the one used. *Coleochæte*, already studied in connection with Chlorophyceæ, and *Nemalion* and *Batrachospermum* among the red Algæ illustrate the same general process.

The comparison of *Microsphæra* with *Albugo* is very instructive in showing how the same conditions have been reached by widely different plants. Both are parasitic, the one living within the host, and the other upon its surface, both deriving nourishment by means of haustoria, in addition to what is absorbed directly through the walls of the filaments.[1] Both bear aerial spores, which are formed by successive abstrictions from vertical mycelial threads, the main difference being that in *Albugo* these must break through the surface-tissue of the host, and are therefore required to grow in groups in order to exert the necessary force, while in the superficial *Microsphæra* they are single and evenly distributed. The conidiospores of *Albugo* sometimes germinate by formation of zoospores and sometimes by direct formation of a filament, while those of *Microsphæra* grow into a mycelial filament at once, a difference whose cause is not known. Both plants form resting spores, but in *Albugo* the protective covering is the thickened wall of the spore; in *Microsphæra* it is a

[1] To see how some of the parasites that are closely related to *Microsphæra* obtain their food consult the drawings and text of an article by Grant Smith on "The Haustoria of Erysipheæ." Bot. Gaz. 29: 153–184.

special shell, enclosing a number of pores in sacs in which the spores are formed.

There is not much known of the manner in which these fruits pass the winter and give rise in the spring to another growth of mildew. It is plain from the structure, however, that the spores escape from the sacs through the thin spot at their apex, but not so evident how they escape from the shell of the fruit and reach the host plant, though their escape is probably secured through the gradual decay of the shell. The appendages we may suppose are of some service in distributing the fruits.

A LICHEN.

Physcia sp. or *Parmelia sp.*

THALLOPHYTES.

PRELIMINARY.

THESE plants may be found growing upon the trunks and branches of trees, upon wooden fences and sometimes upon the ground. *Parmelia* is more common upon hickory-trees. *Physcia* is quite widely distributed. The body of the latter adheres closely to its support. *Parmelia* has a body that is thicker, more extended, and without the prominent radiating lines seen in *Physcia.* The fruiting-cups in *Physcia* are small, with distinct and regular cup margins, those in *Parmelia* being much larger and more irregular. Other Lichens are common to the locations given above.

Species of *Cladonia*, as well as numerous other genera of Lichens, will serve quite well for this study, and should there be time enough, a general study of various forms should be made.

LABORATORY WORK.

GROSS STRUCTURE.

With a piece of the support on which is a piece of the Lichen observe:

1. The color of the Lichen, both of its upper surface and of any parts of the under surface that can be seen. Compare the color of wet and dry specimens.
2. Its form.
3. How it is attached to its support.
4. The fruiting cups (*apothecia*) of various sizes.
5. Make a sketch showing the general form of the Lichen, its relation to its support, and the apothecia.

MINUTE STRUCTURE.

I. Vegetative Characters.

Select a piece of the body that has been moistened, carefully dissect and mount it, and observe:

1. The two elements, the Algæ and Fungi, that together compose the Lichen body.
2. The form and structure of each of these elements, and their similarity to any of the plants previously studied.
3. Cases where the threads of Fungi are closely wrapped about the algal cells.
4. Whether there is any evidence that the Algæ are suffering from their close contact with the Fungi.
5. Make drawings showing the two elements and their relation to one another.

By means of a carefully prepared cross-section of the Lichen body observe:

6. The layer formed of Fungus alone, composing the outer regions.

7. The distribution and relative amount of Fungus and Alga in the interior of the body.
8. The descending processes composed mainly of fungal threads that connect the main body of the Lichen with the support.
9. Compare sections made from different parts of the plant body.
10. Make diagrams showing the distribution of the two elements that compose the Lichen.

II. REPRODUCTION.

1. The Alga.

In the sections and dissections already made, observe:

a. Cases where the algal cells are dividing to form new ones.

b. Whether abundant reproduction is occurring.

c. Compare the reproduction of this Alga with that of *Pleurococcus*.

d. Illustrate reproduction of the Alga by drawings.

2. The Fungus.

By means of dissections or sections cut through the apothecium and perpendicular to its upper surface, observe:

a. The general outline of the cup as seen in section.

b. The general distribution of Algæ and Fungi within it.

c. The surface of the cup formed of parallel fungal threads, some club-shaped sacs—the asci, in which are the ascospores; some slender sterile threads crowded closely about the asci, the paraphyses.

d. The way in which the ascending threads are associated with the Algæ that supply food for the work of reproducing the Fungus.

e. Draw.

ANNOTATIONS.

The group of plants known as Lichens illustrates a close symbiotic relationship between chlorophyll-bearing and non-chlorophyll-bearing plants. The combination known as one Lichen is really two plants living together. The fact that each is a distinct plant has been proven by growing the individuals out of the Lichen combination, and by growing Lichens by bringing together appropriate Algæ and Fungi that did not previously live in such an association.

The Fungus constructs an outside coating that seems to protect the internal hyphæ and the Algæ. The Algæ are so placed as to be well exposed to light, enabling them to manufacture food used by themselves and the Fungi. Doubtless the Fungi assist also in the combination by absorbing materials, and attaching the Lichen to its support.

Difference of opinion exists as to whether the Fungus is a parasite upon the Algæ, or whether both Alga and Fungi are benefited by this habit of living. It is known that Lichens can live in many positions and climates where neither Fungus nor Alga could live alone.

In reproduction each plant is independent, there being no Lichen spore in the sense that a single such spore will produce a new Lichen. It is true that the Fungus uses the Alga to nourish it in its process of reproduction, but the spore formed does not reproduce the Alga.

The forms and habits assumed by Lichens are quite varied. Some are almost invisible scales adhering closely to bark of trees and walls of rocks. Many others

have prominent thallus bodies similar to those here studied. Still others branch extensively, as the "reindeer moss" (*Cladonia rangijerina*), that covers large areas of ground, and the "bearded moss" (*Usnea barbata*), that hangs often in long strings from the branches of trees in many moist regions.

A LIVERWORT.

Riccia.

BRYOPHYTES; HEPATICÆ; RICCIALES.

PRELIMINARY.

THIS plant is found growing upon earth, stones, etc., in very damp places, one species, *R. fluitans*, being a distinctly aquatic form. The plants may be recognized by their thick, dark-green, dichotomously branching small bodies, which are sometimes discoid with numerous rhizoids on the lower side. If *Riccia* cannot be obtained, the common *Ricciocarpus natans* will answer for this study, though some structures are less easily made out in it than in *Riccia*. In addition to the actively growing plant bodies, care should be taken to obtain specimens in which the dark globular *sporophytes* (capsules imbedded in the dorsal tissues) can be seen. Material in which very young sporophyte capsules can be distinguished is likely to contain a few of the sexual organs.

LABORATORY WORK.

GROSS STRUCTURE.

With a good specimen in hand, observe:

1. The general form of the plant.

2. Its method of branching.
3. Its basal and apical regions.
4. Its differentiation into dorsal and ventral sides.
5. The definitely organized midrib.
6. The dark sporophyte bodies sometimes seen along the midrib.
7. Rhizoids, on the ventral surface.
8. Draw.

MINUTE STRUCTURE.

Make a thin transverse section of the plant body (*thallus*) and mount in water.

I. VEGETATIVE STRUCTURES. Observe:

1. Whether a distinct non-chlorophyll-bearing layer (epidermis) is developed above and below.
2. The rhizoids; length, structure, and the way in which they are attached to the lowest layer of body cells.
3. Structure and arrangement of chlorophyll-bearing cells, the lower cells rather compact, while toward the dorsal surface are rows of green cells between which are irregular air-spaces.
4. Draw.

II. SEXUAL REPRODUCTION.

Using the same section observe that:

1. Along the midrib sometimes there may be seen the deeply imbedded flask-like archegonia and the club-shaped antheridia.[1]
2. In the swollen part, the venter of the archegonium, is the central cell, which is the egg, above which is one *ventral*

[1] The sex-organs of *Riccia* are not easily demonstrated. Numerous sections will be required to perform all the work outlined. Specially prepared sections will be found helpful in the work. For making sections of liverwort sex-organs see Chamberlain's "Methods in Plant Histology," p. 89.

canal cell, and a row of *neck canal cells*, enclosed by the neck wall cells. In archegonia which contain fertilized eggs the canal cells have disappeared, having become disorganized to permit the access of the sperms to the eggs.

3. Draw.

Observe also:

4. The antheridium, a club-shaped organ, consisting of a layer of wall cells and many small sperm mother-cells. In fresh material sperms may sometimes be seen as they escape from the antheridium.
5. Draw.
6. Archegonia which contain germinating oospores.
7. Draw.

III. Asexual Reproduction.

1. If the section is especially favorable, note the different stages in the germination of the oospores, resulting finally in the formation of the fully formed sporophyte (or *sporogonium*), consisting of:

   (*a*) A single outside layer of cells constituting the wall which early disappears, and

   (*b*) A mass of asexual spores.
2. Draw.

ANNOTATIONS.

The general form and structure of *Riccia* suggest *Coleochæte*, the highest member of the Chlorophyceæ that we have examined, but *Riccia* is very much more highly differentiated both for nutritive and reproductive work. The prostrate branching body of *Riccia* is differentiated in that it is distinctly dorsiventral, has on its ventral side rhizoids which perhaps assist in obtaining water and its solutes and serve also to anchor it. The

plant body has further specially organized chlorophyll-bearing cells and protecting epidermal cells. Altogether the plant is very much better organized for chlorophyll work than is *Coleochæte.*

The sexual organs of *Riccia* are multicellular and are nearly enclosed by vegetative tissues. They are not imbedded when they begin to develop, but become so as the adjacent tissues grow over them. The biciliate sperms are discharged on the upper surface of the plant and gain entrance to the egg through the canal of the archegonium.

After fertilization the egg does not pass through a resting period, but soon begins to germinate without being set free from the venter of the archegonium. It develops a globular mass of cells, of which the outermost layer produces no spores (*i.e.*, it is sterile), but encloses the spore-forming or *sporogenous* tissue within. This *sporogenous* tissue finally forms a mass of heavy rough-walled spores, that are eventually set free by the early disappearance of the wall and ultimately by the decay of the old plant body. At the return of favorable conditions for growth these spores produce new *Riccia* plants.

It is evident that we have two kinds of spores formed, one as the result of the union of the sperm and the egg, and another as the result of development of this oospore. One is sexual, the other asexual. The number of asexual spores formed is quite large relatively, and serves very greatly to increase the number of new plants that may come from one oospore. The *sporogonium*, the structure formed from the oospore, is, when ripe, little more than

a mass of spores, but in higher plants it will be seen to have developed into the structure we ordinarily regard as the plant body. In *Coleochæte* the oospore becomes enclosed by a heavy wall of cells, and finally forms a mass of asexual spores that form new *Coleochæte* plants.[1] Even in it we have the same sort of alternation between sexual and asexual spores that we have in *Riccia*, while we also have similarities existing in the two plants both as to the form of the plant body and the organs producing asexual spores. The structure that grows from the oospore is little more than an organ for producing asexual spores, but it is destined in the course of evolution to become more and more important until it is the dominant phase in the plant's life-cycle.

[1] It must be borne in mind that in *Coleochæte* the protecting tissue about the resting oospore did not come from the oospore, as is true in *Riccia*. See Davis on "The Origin of the Sporophyte," in the American Naturalist, 37: 411.

MARCHANTIA POLYMORPHA.

BRYOPHYTES; HEPATICÆ; MARCHANTIALES.

PRELIMINARY.

THIS liverwort is common throughout America and Europe. It grows among grass, over wet soil or rocks, in drier spots along walls and fences, and occasionally in more exposed situations, but is most luxuriant in damp shady places. The vegetative part consists of a flat, green, leaf-like, dorsiventral body, on the under side of which are rhizoids that hold it close to the ground. Often the plants may be distinguished by the presence of reproductive branches that arise as stalks from the flat part of the main body, and bear expanded heads at their upper ends. Besides these there are often small sessile cups, the cupules, on the upper surface of the stems. On the dorsal surface the plant is divided into very small diamond-shaped areas. When the reproductive branches and cupules are present *Marchantia* may easily be recognized. *Conocephalus conicus*, another liverwort that grows in damp places and bears a strong general resemblance to *Marchantia*, may be distinguished by its much more prominent diamond-shaped areas, and the more prominent pore that is visible to the naked eye

within each area. *Lunularia cruciata* is not uncommon in greenhouses. It may be distinguished by its crescent-shaped cupules, lacking a border on one side.

Marchantia may be grown in the laboratory. In collecting material for study, care should be taken to obtain fertile plants with young heads; some female heads just large enough to be seen in the sinus at the tip of the branch should be collected. Also a good supply of older heads of both flat and radiate forms will be needed.

LABORATORY WORK.

GROSS STRUCTURE.

I. Vegetative Structure. By examining one or two specimens, observe:

1. The general form and color of the body.
2. Its manner of branching.
3. The rhizoids.
4. The diamond-shaped areas, with a central air-pore in each. These are seen best with a small lens.
5. Draw.

II. Reproductive Structures. Observe:

1. In rather large patches of *Marchantia* note how the younger parts of the plants have advanced, and have been left free as new plants by the death of the older portion.
2. Two kinds of heads on the upright branches. The flat disk-like one is the *antheridial* head, and the radiate or fingered one is the *archegonial* head. Determine whether both kinds are borne on the same plant.
3. The cupules, their form, and where borne; the small green buds, the *gemmæ*, within the cupules.
4. Make general sketches illustrating reproductive structures.

MINUTE STRUCTURE.

I. Vegetative Structure.

Remove the outgrowths from the under surface on different parts of the plant, mount, and observe:

1. Flat outgrowths; note where and how attached.[1]
2. Two kinds of tubular rhizoids, one with peculiar thickenings within them.
3. Draw.

Make a thin cross-section of the plant body, and observe:

4. Lower epidermis from which the rhizoids, etc., arise.
5. A compact mass of almost or entirely achlorous (without chlorophyll) tissue directly above this epidermis.
6. Special chlorophyllose cells, often in alga-like chains that extend from the compact tissue toward the upper surface.
7. The upper epidermis, in which sections of the pores will sometimes be seen.
8. Just beneath the upper epidermis, and extending down to the compact sterile tissue, the columns of pale cells, which are sections of the partitions which divide the upper part of the plant into diamond-shaped air-chambers, in which are the chains of chlorophyllose cells.
9. Draw.

II. Vegetative Reproduction.

1. The cupules and gemmæ. Remove and study the form of gemmæ. Observe:
   - *a.* The flattened body.
   - *b.* The pair of notches indicating the points of most active growth.
   - *c.* The scar at the point where the gemma separated from the stalk upon which it grew.

[1] These plate-like outgrowths are regarded as primitive leaf-like structures.

d. Make a vertical section through the base of the cup, and observe stages in the development of gemmæ.

e. Draw.

III. Sexual Reproduction.

1. The antheridial branch, and antheridia.

Select an antheridial branch in which the stalk is rather large and make a cross-section of it. Observe:

a. The general outline of the section.

b. The hairs which fill the grooves. Follow some of the strands of the hairs downward and upward upon an uninjured stalk and determine where they terminate.

c. Sketch the section.

Make radial vertical sections of the head, and observe:

d. The prominent flask-like chambers, with their necks opening upon the upper surface, each containing an antheridium within it.

e. The antheridium; its stalk; wall of one layer of cells, within which are many squarish cells, the sperm mother-cells.[1]

f. The air-cavities and tissues which compose the body of the head.

g. Young and old stages of antheridia.

h. Draw enough of the section to show these structures.

2. The archegonial branch, and archegonia.

Select both old and young branches, and observe:

a. The appearance of young branches at the time they first may be distinguished from the thallus.

Then carefully dissect the young head and mount, or by means of a radial vertical section observe:

[1] With fresh material often an abundance of swimming sperms may be obtained. This may be done by placing a fresh ripe head in a drop of water, at which time thousands of sperms may escape from their antheridia. They may be studied first while moving, and then staining with iodin will give an excellent view of their structure.

b. The archegonia, which in such material usually appear in various stages of development. With a fully formed archegonium locate the following parts:
  i. The elongated basal region, the *stalk.*
  ii. The swollen region, the *venter.*
  iii. The elongated region, the *neck.*
  iv. Within the venter, the *egg.* Frequently it will be seen that the egg has been fertilized and has already begun to germinate.
  v. Within the neck, the *neck canal cells.*
  vi. The cell between the neck canal cells and the egg, the *ventral canal cell.*

c. Arising from the region near the base of the archegonium, an outgrowth, the *perianth,* which later develops about the archegonium.

d. Draw a fully formed archegonium.

e. Draw stages in the development of an archegonium.

f. Note the changes in the size and form of the archegonial heads as they mature.

IV. The Sporophyte and Asexual Reproduction.

Make sections of an archegonial head that is more mature and study the changes that occur in the germination and development of the oospore. Observe:

1. The first division of the oospore by the *basal wall.*
2. Trace the changes in form of the body and the increase in the number of cells until the number can no longer be determined.
3. Draw.

From old heads dissect out the fully formed sporophytes enveloped by the perianth, and observe:

4. The three distinct regions, *foot, stalk,* and *capsule.* Draw.
5. The spores.

6. The *elaters*, elongated cells, with spiral thickenings. Remove the cover-slip and allow the crushed specimen to become dry as you watch it, and observe:
7. The behavior of the elaters.
8. Draw.

ANNOTATIONS.

From a morphological point of view *Marchantia* is a plant of unusual interest, on account of its remarkable degree of differentiation. The upper part of the prostrate gametophyte has differentiated highly specialized tissues for chlorophyll work, the whole upper surface being divided into air-chambers in which we find chlorophyllose cells, that show a striking resemblance to the green Algæ. This air-chamber is open to the exterior by a pore whose edge is formed by four layers of cells. The lower part of the body is differentiated for the work of support and storage of foods, and must also transfer materials from the ventral surface up to the chlorophyll tissue.

As the gametophytes grow they branch dichotomously, the older parts steadily dying away, thus giving rise to separate plants. Vegetative reproduction is also carried on freely by means of gemmæ, designed especially for the purpose, and borne in special organs. The plant is extremely successful in its vegetative reproduction.

The sexual reproduction also shows an advance over *Riccia*. Special branches bear the sexual organs, the sexual organs themselves being more complex than in *Riccia;* furthermore, one plant bears but one kind of sex organ, i.e., the species is diœcious.

Fertilization takes place within the venter of the archegonium, and the oospore germinates in the same

location. The oospore is first divided by the basal wall into two regions, one of which develops the foot of the sporophyte, and the other develops the capsule. The wall layer of this capsule is sterile, and within this the spores are produced. Distributed about among the spores are elaters, specialized structures that move the spores about and usually hold several of them together. It will be noted also that the sporophyte of this plant has relatively more sterile tissues than has the sporophyte of *Riccia*, there being in addition to the sterile walls and elaters, the foot and stalk, which place the spores in a position more favorable for distribution.

A LEAFY LIVERWORT.

Porella.

BRYOPHYTES; HEPATICÆ; JUNGERMANNIALES.

PRELIMINARY.

Porella is common in temperate regions, appearing as a moss-like growth upon logs, tree-trunks, etc. It lies almost prostrate, with the tips of branches somewhat turned up. It can undergo extreme drying and retain its vitality. Material collected for study may be preserved by drying or in the ordinary preserving fluids. For the study there should be specimens showing the vegetative structures, and also some showing reproductive organs. The latter may usually be detected by the tufted arrangement of the leaves at the tips of branches on which there are reproductive organs. The archegonia and antheridia are not borne on the same branches.

LABORATORY WORK.

GROSS STRUCTURE.

With a few specimens in hand and by use of a hand-lens observe:

1. The central axis or stem of the plant from which arise:

2. The leaves; note the way in which they are attached to the stem, the number of rows, their positions, and their arrangement at the tips of branches.
3. Rhizoids; their number and position.
4. Draw.

MINUTE STRUCTURE.

I. Vegetative Structure.

Mount two or three of the leaves and observe:

1. General structure, thickness, arrangement of plastids, presence or absence of epidermis and midrib.
2. The way in which the leaves join the stem.

Mount some of the rhizoids, and observe:

3. Their general structure; compare with the rhizoids of *Marchantia*.
4. Draw.

II. Reproductive Structure.

1. Select branches on the tips of which the leaves have formed close tufts, carefully dissect away the leaves and search for archegonia [1] in different stages of development. Draw, showing archegonial base, venter, neck, neck canal cells, and egg.
2. On other branches, having leaves more regularly imbricate than the vegetative ones, search for the antheridia, each made up of a long stalk bearing a spherical body in which sperms are formed. It is frequently possible also to observe good stages in the development of the antheridia. Draw.
3. On old archegonial branches find the sporophytes, each bearing a general resemblance to an antheridium. Search

[1] Specially sectioned and stained preparations cut parallel to the stem of the branches will be found advantageous in studying archegonia, antheridia, and sporophytes.

for oospores just beginning to develop the sporophyte, and also old sporophytes which contain ripe spores. Draw.

ANNOTATIONS.

The plant body of the leafy liverworts differs from that of the forms already studied in that it has specialized stem and leaves, better adapting it for chlorophyll work. The leaves are arranged in three rows and are simply lateral outgrowths from the stem. The rhizoids are comparatively few in number and arise from the ventral side of the stem at its base. Although the plant has basal and apical regions and the leaves are arranged around the stem, it is essentially dorsiventral because of the unlikeness of the leaves above and below, and of the occurrence of rhizoids chiefly on the ventral side. The plant is prostrate, though the tip sometimes becomes erect. In some ways the plant is far better organized for nutritive work than any that have yet been considered.

In *Porella* the branches that bear the reproductive organs are not set apart entirely for reproductive work, as was the case in *Marchantia.* In general structure the archegonium is essentially similar to that of *Marchantia,* while the antheridium is not sunk beneath the surface as in the other liverworts studied, but is free and has a supporting stalk. Fertilization takes place and the oospore develops into the sporophyte as in *Marchantia.* The sporophyte has distinct foot, stalk, and capsule regions. When it has ripened its globular mass of spores they are set free by having the capsule split into four valves, and eventually develop new leafy plants.

ANTHOCEROS.

BRYOPHYTES; HEPATICÆ; ANTHOCEROTALES.

PRELIMINARY.

THIS liverwort is not so common as are the two already studied, but may be found frequently on wet ground or stones in deeply shaded places or even in dense growth of grass. Its thallus is usually smaller than that of *Riccia*, and often appears as a small scale-like green body, adhering very closely to its support. The plant is easily identified when sporophytes are present, since they are prominent dark green slender columns which stand upright from the flat thallus. Material for study should consist of the thallus, both in vegetative and reproductive periods, and of those bearing sporophytes.[1]

LABORATORY WORK.

GROSS STRUCTURE.

With some specimens in a small dish of water observe:

1. The size of the thallus as compared with *Riccia* and *Marchantia*.
2. The form.
3. Thickness, at the margins and along the midrib.

[1] Owing to the peculiar importance of *Anthoceros* in illustrating the development of the plant kingdom, suitable material should be obtained from a supply house in case the local region does not furnish it.

4. Rhizoids: number and distribution.
5. Draw.
6. Sporophytes arising from the thallus. Note especially the form and relative size of all parts of the sporophyte, and whether its tip is split or entire.
7. Draw.

MINUTE STRUCTURE.

I. Vegetative Structures.

By use of sections of the thallus cut at right angles to the surface and parallel to the midrib observe:

1. The relatively simple structure of the thallus.
   a. Number of cells in thickness at midrib and margin.
   b. Absence of epidermal tissue.
2. Origin of rhizoids.
3. Draw.

II. Sexual Reproduction.[1]

1. Archegonia and antheridia, somewhat similar to those of *Riccia*, though the antheridia arise from within the gametophyte tissue (endogenous).
2. The oospore beginning to germinate to form the sporophyte.
3. Draw.

III. Asexual Reproduction.

1. The base of a well-developed sporophyte. Note especially the foot, with its rhizoid-like processes which penetrate the tissues of the thallus.
2. Draw.

By use of a section cut lengthwise through the sporophyte observe:

[1] Owing to the difficulty of observing these points, prepared slides specially stained are indispensable and should be used as a means of demonstrating the structures mentioned in 1 and 2.

3. That the structure is organized into three regions, an outer protecting, supporting, and chlorophyll-bearing region; an axial region; and between these the spore-forming or sporogenous region.
4. In the sporogenous region, the stages in the process of spore formation, from youngest sporogenous tissue in the lower part of the sporophyte, to fully formed spores toward the tip.
5. Draw, showing different kinds of tissues, and stages in spore formation.

ANNOTATIONS.

The gametophyte body of *Anthoceros* is very much more simple than that of *Riccia.* It has no special air-chambers or air-pores, is but a few layers of cells in thickness in the thickest place, and in every way suggests a very simple type of plant-body. The archegonia and antheridia are simple in structure. The archegonia develop from surface cells and become surrounded by gametophyte tissue while antheridia are endogenous in origin. The fertilized egg begins its development while imbedded in the archegonium. From this oospore there develops a sporophyte which is much more complex than any heretofore considered. The sporophyte is distinctly stalked and bears at its lower end structures like short rhizoids which serve to increase the surface through which the foot absorbs nourishment from the gametophyte. In addition to this there are stomata, like those of higher plants, and chlorophyll that enables the sporophyte to manufacture some of its own food. It is evident that the sporophyte is somewhat independent, and to become completely so it needs but to have the root-

like foot become adapted to the ground, and the chlorophyllose tissue increased. This course of development for the foot, however, was never worked out, or at least has not survived. This is the highest type of sporophyte found in the liverworts, and gives a hint of the independent sporophyte of the Pteridophytes soon to be considered.

The asexual spores of *Anthoceros* are formed in the extended portion or capsule, the oldest being at the top and the youngest below Only a cylinder of tissue is used to produce spores, all the remaining part being differentiated to serve other functions. It is evident that we have had a relative, though probably not an absolute, diminution of the amount of sporogenous tissue, and corresponding increase of sterile tissues from the lowest to the highest liverworts. This has been accompanied by increase in the complexity of the sporophyte body, and constant approach toward independence.[1]

[1] See article by Bradley Moore Davis on "The Origin of the Sporophyte," already cited in connection with *Coleochæte*.

A MOSS PLANT.

Funaria hygrometrica or *Atrichum undulatum.*

BRYOPHYTES; MUSCI; BRYALES.

PRELIMINARY.

To those who are entirely unfamiliar with the mosses, the different species appear quite similar. There are many species besides the two mentioned that are suitable for laboratory study, but the ones mentioned are abundant and are more readily obtained in all their stages than are some of the others. Although the outline has been prepared with a view to the use of *Funaria* or *Atrichum*, it may be adapted readily to any other common form.

Atrichum is widely distributed and very common, forming carpet-like patches in woods and on shady banks. *Funaria* has even a wider distribution than has *Atrichum*, and has an additional advantage as a type for study in that it is more readily grown in the laboratory. It is found especially where fires have burned, or on cinder paths. As the reproductive organs of *Funaria* are formed rather early in the growing season, it is necessary to collect specimens in the latter part of March and during April, in order to obtain plants showing good antheridia and archegonia. The antheridial plants

(if the plants are diœcious, as is often the case in mosses) may be distinguished by the expansion of the terminal leaves, thus giving the ends of the plants something of the appearance of inverted umbrellas. Also the clusters of reddish-brown antheridia on the ends of the stems may often be seen. Archegonial plants are less distinctly marked. They have the leaves so arranged as to enclose the tip of the stem, and their presence is often indicated by the development of the young sporophytes from the tips of some leafy shoots.

The sporophytes may develop quite early, and ripe spores from them may be scattered and begin a new life-cycle early in the spring. Specimens of antheridial and archegonial plants, and of young and mature sporophytes should be collected and preserved in alcohol or formalin. Plants with mature sporophytes should also be preserved dry, from which ripe spores can be collected and sown on moist earth in the laboratory, since the young stages desired can be easily grown. Some specimens of antheridial and archegonial plants and immature capsules should be prepared for sectioning.

GROSS STRUCTURE.

Observe:

1. The vertical *stem*; usually unbranched.
2. The leaves which are borne by the stem: how attached to it.
3. The *rhizoids*.
4. The different way in which the leaves are arranged at the tip of the stalk.
5. On some plants, the sporophyte with slender stalk, *seta* bearing the *capsule*.
6. Draw.

MINUTE STRUCTURE.

I. Vegetative Structure.

Mount and examine under low or high power, as may be needed to demonstrate the structures and observe:

1. The rhizoids; their structure and how they arise from the basal end of the stem. Draw.
2. The leaves.
   a. Thickness in various parts.
   b. Specially differentiated cells along middle of leaf.
   c. Prominent chloroplastids within cells.
   d. Draw, showing in detail the different kinds of cells that compose the leaf.
3. The stem.
   a. How stem and base of leaf are united.
   b. Whether stem bears chlorophyll.
4. The protonema. Examine some of the earth in which the moss plants grew, or some of that in which mature moss spores have been sown some weeks previously. If the material is good, it should show:
   a. The alga-like structure of the protonema; cells with chloroplastids; method of branching. Draw.
   b. Buds arising from protonema and gradually developing into the leafy shoots. Draw stages illustrating this development.

II. Sexual Reproduction.

1. *Antheridium.* From one of the male plants carefully remove the leaves, allowing at least a part of the antheridia to remain on the stem. Observe:
   a. The position and general arrangement of the club-shaped antheridia, and
   b. The paraphyses which stand among them and extend above them.

c. The detailed structure of a single antheridium. When studying fresh material it is often possible to obtain antheridia just ripe enough to allow the sperms to escape at the time the antheridia are mounted in water. If possible, obtain such a preparation, note the structure and behavior of the sperms. Note where and how the antheridium opens. Draw.

2. *Archegonium.* From female plants carefully remove the leaves, and locate the archegonia. Observe:
   a. The attachment of the archegonia; the structure of the paraphyses associated with the archegonia. With a single archegonium well mounted observe:
   b. Its general form and structure, much as in liverworts; the basal stalk; the swollen region, *venter;* the elongated region, the neck, with a central row of *neck canal cells;* within the venter a spherical cell, the *egg;* immediately above the egg and below the neck canal cells the *ventral canal cell.*
   c. Draw.
   d. Try to find archegonia in which the egg is fertilized, and determine how the sperm obtained entrance to the egg.
   e. In sections of old archegonia observe the early divisions of the oospore as it is germinating.
   f. Draw.

III. The Sporophyte and Asexual Reproduction.

1. Observe and draw a young sporophyte just emerging from the leaves.
2. Carefully remove the young sporophyte by pulling it out of the stalk of the leafy shoot, and observe:
   a. The elongated stalk, the *seta,* at the lower end of which is the sharpened foot that was imbedded within the stalk of the leafy shoot.

b. The hood, *calyptra*, that envelops and protects the young sporophyte. Determine its relation to the archegonium.

c. Draw.

3. The adult sporophyte. Observe:

a. The elongated stalk, the *seta*.

b. The enlarged tip, the *capsule*.

c. The *calyptra*, frequently fallen away in *Funaria;* but it may be found in some species at maturity.

d. Draw, showing leafy shoot and complete sporophyte.

e. The details of the structure of the capsule. By carefully cutting off and mounting the end of the capsule observe:

i. The *operculum* or lid, covering the mouth, and early covered by the calyptra.

ii. The *peristome*, fringing the mouth inside, composed of projections, the teeth. Some mosses have two and some one row of teeth. Observe the number and arrangement of the teeth and the differences between the two rows, if present.

iii. Draw.

iv. The spores, within the capsule.

v. By means of prepared sections of young capsules, both transverse and longitudinal, study the position and extent of sporogenous and sterile tissues, the stages in the development of spores, and the nature of the teeth.

vi. Draw.

ANNOTATIONS.

The gametophyte body of the moss is distinctly unlike that of the liverworts studied. The asexual spores of some of the liverworts in the earliest stages of germination

form structures not unlike the moss protonema, but almost directly they pass into the dorsiventral liverwort body. In the true mosses the protonema may persist for a long time before giving rise to a leafy shoot. But this phase of the gametophyte is purely vegetative, since it produces no sexual organs and consequently cannot produce a sporophyte. It may branch and extend itself, thereby increasing in vigor and probability of producing more than one leafy axis. It may also serve to carry the plant through unfavorable periods.

With the development of the leafy shoot from the buds on the protonema, there appear structures not equalled in complexity by the gametophytes of the liverworts. The upright stem supports a system of leaves that are radially arranged, thereby exposing the chlorophyll to the light in a better way than has yet been done. At the lower end of the stem are anchoring organs, the rhizoids. It may be that these absorb materials from the earth and carry them to the stem, through which by means of specialized tissues they may be transported to the leaves. The stem is almost entirely relieved of chlorophyll work and is given over mainly to the work of support, its form and structure being adapted to this function. The leaves show distinctly differentiated conducting tissues, which also help stiffen the leaf. The margin of the leaf is also strengthened in some cases.

The sexual organs are borne at the apex of the gametophyte stalk and are more or less enclosed by the paraphyses that grow among them. Mosses may be *monœcious* or *diœcious*. The oospore begins its development within the venter of the archegonium, and its growth stimulates

the venter of the archegonium, the stalk, and a part of the adjacent tissues of the axis to grow so as to form a sheath around the developing sporophyte. But the sporophyte soon outgrows this envelope and elongates to such an extent that it breaks it near the base. As the sporophyte stalk continues to grow, its end carries upward this sheath as the calyptra. Meanwhile the lower end of the sporophyte becomes imbedded in the axis of the leafy shoot, from which it absorbs nourishment for the development of the entire sporophyte. Thus the sporophyte is parasitic upon the gametophyte. It may do a little in manufacturing food by means of chlorophyll, for it has stomata and can absorb carbon dioxid, but it must get its water and salts from the gametophyte.

A relatively small amount of tissue is sporogenous, and there exist in the sterile tissues much more effective devices for protecting sporogenous tissues, and for distributing spores, than existed in the liverworts. It is evident that in this entire plant we have quite an advance in the division of labor among the parts of the plant, and a consequent increase in the quality and quantity of work accomplished.

It will be remembered that in the Alga *Coleochæte* after fertilization of the egg the tissues adjacent to it are stimulated to growth so that they soon enclose the base of the oogonium. In *Riccia* after fertilization the tissues continue to grow about and nourish the developing sporophyte. About the base of the archegonium of *Marchantia* there grows after fertilization an extensive sheath that finally completely encloses the fully formed sporophyte. In the mosses, when the fertilized egg has

been formed some of the gametophyte structures begin an extensive growth that bears an important relation to the sporophyte. This stimulating effect upon the gametophyte through fertilization of the egg is significant, and when considering higher groups there will be occasion to refer to the facts here presented.

THE BRACKEN-FERN.

Pteris aquilina.

PTERIDOPHYTES; FILICALES; FILICINEÆ.

PRELIMINARY.

THIS fern is general in its distribution, being found under a variety of conditions. The leaves stand erect from an underground stem, and branch rather extensively. They sometimes become three or four feet long and often develop in such numbers as to produce quite dense growths. The underground stem is sometimes many feet long, and may have leaves arising from its tip and from many side branches. On the under side of leaflets the sporangia appear, being protected by a fold of the leaf margin, and when ripe appear reddish brown.

Occasionally one may find the gametophytes on damp earth near the adult plants. They may range in size from one or two millimeters to one or two centimeters across. They are irregularly heart-shaped and are held close to the soil by a system of rhizoids that arise from the lower surface of the gametophyte body. In some cases a primary leaf of a young sporophyte may be seen

arising apparently from the notch at the forward end of the gametophyte.

The following materials should be collected: the underground stem or rhizome with the roots that grow from it, care being taken not to tear away the fine roots; a piece of young rhizome suitable for sections, the latter, and a good supply of roots with their tips uninjured, being preserved in formalin or alcohol and a few young roots preserved for microtome sectioning; a supply of leaves, with and without sporangia, some being pressed, some being preserved in alcohol or formalin, and some pieces of leaves bearing sporangia being prepared for sectioning; a supply of ripe sporangia with their spores, preserved dry.

About six weeks before the laboratory work is to be begun some of the spores should be sown on damp earth or sand in a dish that should be kept covered. This sowing will usually furnish a supply of gametophytes for laboratory study.

Pteris cretica and *P. cristata*, common greenhouse ferns, will serve well for this work, as will also the maidenhair fern, *Adiantum pedatum*. Numerous other ferns will furnish excellent material in case none of the above can be obtained.

GENERAL STRUCTURE.

I. The Rhizome and Roots. Observe:

1. The flattened dorsiventral stem, the upper and lower portions being divided by prominent ridges.
2. The roots arising from the ventral surface and sides.
3. The roots, each (if uninjured) with a small root-cap at its tip.

4. The *nodes* and *internodes* of the stem; the nodes are indicated by the growth of a leaf at each, alternately on the right and left sides: the intervals between the nodes are the internodes.
5. Draw.

II. The Leaf. Observe:

1. The leaf-stalk, or *petiole*, arising from the rhizome and frequently miscalled the "stem"; its strength and general appearance.
2. The system of branching.
3. The leaf *blades*, or *leaflets*.
4. The arrangement of veins in the blades, *venation*.
5. The sporangia, and the folded edge of the leaflet that protects them. When sporangia grow in clusters each cluster is called a *sorus* (pl. *sori*). When there is an epidermal outgrowth above a sorus it is called an *indusium*. In *Pteris* the folded leaf margin is a false indusium.
6. Draw.

MINUTE STRUCTURE.

I. The Stem.

Make a thin transverse section of the stem and study the general regions by means of the low power, and the cell structure by means of the high power. Observe:

1. *Epidermal* region, consisting of a single layer of cells.
2. The *sclerenchyma*, the heavy-walled strengthening tissue beneath the epidermis.
3. Within this outer layer of sclerenchyma, the irregularly semicircular *fibrovascular* region enclosed by a layer of cells, the bundle-sheath. Within the bundle is composed of very heavy-walled cells (*xylem*), and others (the *phloem*) with much thinner walls. Study xylem and phloem cells and observe their distribution with reference to one an-

other. Enclosed by the fibrovascular region is a mass of *axial sclerenchyma* whose cells resemble those seen in 2.

4. Diagram the entire section and draw in detail a narrow strip across it, so as to show all the kinds of tissues. Make a longitudinal section of the stem, and identify:
5. The various regions observed in the cross-section. Draw.

II. The Root.

Make a transverse section of one of the larger roots, study it, and make a diagram, showing:

1. The epidermal region.
2. The parenchyma, composed of cells of approximately equal dimensions.
3. The sclerenchyma, resembling that of the stem.
4. The fibrovascular bundle and its bundle-sheath. Notice the starch stored in the above tissues. Select some roots with uninjured tips and make longitudinal sections of the tip.[1] Observe:
5. The layers of the root-cap.
6. Under the root-cap in the median section a large triangular cell, apex inward, the *apical cell*. Notice that the cells adjacent to the inner faces of the apical cell have evidently been derived from it by partitions parallel to its faces.
7. Draw the tip of the root, including the apical cell and the root-cap.

III. The Leaves.

1. Epidermis. Lift the epidermis of the lower surface with the point of a needle or scalpel, seize it with fine forceps and strip off a small piece, mount it with the outer surface upward, and observe:
   a. The very irregular epidermal cells and the way they dovetail into one another.

[1] The best results will be obtained if serial microtome sections are at hand.

b. Here and there narrow slit-like *stomata*, each consisting of an opening bounded by two crescentic cells, the *guard-cells*.

c. Along certain lines (over the veins) the different shape of the epidermal cells.

d. The chloroplasts, especially in the guard-cells.

e. Make a drawing showing these points.

f. Examine in the same way the epidermis of the upper surface of a leaflet; note the absence of stomata.

2. Make a transverse section of a leaflet,[1] mount, and observe:

a. The upper and lower epidermis; the sections of stomata appearing in the latter. Note also the substomatal chamber within the green tissue.

b. The *mesophyll*, the chlorophyll-bearing tissue.

c. The veins.

d. Draw.

IV. Sporangia and Spores.

From a ripe sorus remove and mount some sporangia. In a perfect specimen observe:

1. The stalk on which it was borne.
2. The form of the main body or spore-case.

a. On one edge note the row of heavy-walled cells, the *annulus*. Where are its ends?

b. The cells that form the rest of the wall.

3. The spores.
4. Draw.
5. Place on the slide some sporangia that have been moistened in water, allow them to become dry as they are observed with the low power, and determine just how the sporangium acts in expelling spores. Make diagrams illustrating the changes in position of the annulus and the side walls during this process.

[1] These leaf sections will be most satisfactory if made from material imbedded in paraffin.

If good microtome sections of young sori can be had, study and draw, showing the development of the sporangia, observing the following stages:

6. The young stalk with cell divisions at right angles to its long axis.
7. An oblique division forming an apical cell.
8. The primary wall cells surrounding the single archesporial cell.
9. Completed wall cells, surrounding sporogenous cells.
10. Sporangia containing spore mother-cells, and others with spores.

V. THE GAMETOPHYTE AND SEXUAL REPRODUCTION.

1. The gametophyte body. Examine the soil or brick upon which spores were sown some three or four weeks previously. Observe:
   a. The green coating given by the young gametophytes (*prothallia*) developing from the spores. Mount some of the material and study the development of the gametophyte, observing the following stages:
   b. Spores just beginning to germinate, showing the protonemal or filamentous structure, and the first rhizoid. Draw.
   c. Specimens in which the filament begins to broaden by means of longitudinal and oblique cell-walls, as well as by the transverse ones that first appeared. Such stages should show the early appearance of the apical cell; also the formation of rhizoids. Draw.

   In material six to eight weeks old examine:
   d. Fully formed gametophytes, showing the characteristic heart-shaped body, the deep apical notch, the rhizoids on the under side of the dorsiventral body. Diagram the body, and draw a few cells in detail.
2. Sex organs and gametes.
   a. Antheridia.

On rather young gametophytes antheridia may often be seen extending outward from almost any of the marginal cells; on old gametophytes they do not grow in this position, but on a definite part of the under surface of the body. They may be most easily studied on young gametophytes. Locate good antheridia in such position as to be seen from a side view. Study, observing:

i. The short antheridial stalk, and how it arises from the body.
ii. The wall cells; note that the tip cell is arranged so as to make a ready opening for the escape of sperms when ripe.
iii. The centrally placed sperms or sperm mother-cells.
iv. Draw.

By mounting in water some rather dry gametophytes that are producing antheridia, it will often be possible to obtain sperms in the process of escaping. Make such a mount, and observe:

v. The form and movement of the sperms. Stain with iodin, and observe:
vi. The cilia.
vii. The body of the sperm.
viii. Draw.

b. Archegonia.

Mount fully formed gametophytes with the ventral surface uppermost, and observe:

i. The archegonial necks protruding from the surface, and curved away from the notch. Sometimes the opening into the neck can be seen. Draw. By means of microtome sections cut perpendicular to the surface and along the longitudinal axis of the gametophyte, study the structure of the archegonium, observing:

ii. The imbedded venter, from which
iii. The recurved neck extends.
iv. The egg, ventral canal, and neck canal cells.
v. Draw.

VI. The Young Sporophyte.

By means of sections made as for 2. b. ii. study early stages in the development of the sporophyte. Observe:

1. Recently fertilized eggs, in which the first division wall has appeared. Note its direction and how it divides the oospore. Draw.
2. The direction of the second division walls, and the resulting quadrants. Each of these quadrants forms a definite organ of the young sporophyte embryo, foot, stem, leaf, or root. Draw.
3. Some older sporophyte embryos in which some of the embryonic organs are discernible. Draw.
4. With some fresh material search for specimens in which the first leaf of the young sporophyte is emerging from the notch of the gametophyte, while the real stem is beginning to grow downward, and the foot still holds the young plant to the old gametophyte. Draw.

ANNOTATIONS.

A striking difference between *Pteris* and any Bryophyte studied is seen in the fact that in ferns the mature gametophyte and sporophyte generations are able to live independent of one another. Each has organs relating it to the surrounding medium, and each has chlorophyll by means of which it can manufacture food from what it can absorb. The gametophyte is for a brief time dependent upon food stored in the spore that forms it, and the sporophyte

foot absorbs from the gametophyte the nourishment for the embryo sporophyte, but each soon becomes able to provide for itself.

The gametophyte is not so large or complex a structure as that of the Bryophytes. It is dorsiventral and in several ways greatly resembles the gametophyte of *Anthoceros*. In the way in which it develops it also shows striking resemblance to Bryophyte gametophytes. The antheridia, which are usually formed on the basal part of the gametophyte, are outgrowths from surface cells, and are not so complex as were those found in Bryophytes. The sperms are spiral, bear many cilia, and move with great rapidity. The archegonia have their venters deeply embedded within the gametophyte, but their necks protrude and are so directed that when the tips open they are favorably placed to admit the sperms.

The first division of the oospore is effected by means of a wall that runs at right angles to the surface of the gametophyte and almost parallel with the long axis of the archegonium. The next wall runs at right angles to the first, and the two divide the oospore into four quadrants, an outer and inner anterior, and an outer and inner posterior. The outer anterior produces the first leaf; the inner anterior produces the first stem; the primary root is produced by the outer posterior, and the inner posterior produces the foot. The embryonic foot and embryonic root disappear, the real stem becoming the rhizome from which the secondary roots arise. The primary leaf is also transient, new and larger leaves being formed annually from the rhizome. It is evident that this definiteness in the origin of organs from the

parts of the oospore is a marked advance over Bryophytic conditions.

The sporophyte, which in Bryophytes is always parasitic, is here a prominent structure bearing extensive leaf surfaces, thereby exposing much chlorophyll to the light. This increase in chlorophyll work is necessarily accompanied by an increase in mechanical and conducting tisues. The conducting system is far superior to anything seen in Bryophytes, as is also the mechanical system. The leaf-stalk supports the chlorophyll tissue, the real stem being underground, where it serves as the axis for the secondary root system, and also serves as a storage region for surplus food.

For the development of the organs of the plant, gametophyte, root, stem, etc., growth is localized; and in each such locality there is present a specialized cell, the apical cell, from whose faces new cells are cut off by partition-walls. After each division it enlarges, and repeats the process on another face. Adjacent cells also divide and grow, and this may occur anywhere. But the apical cell is very active in division, and thus marks a region of growth.

Sporangia arise from a single surface cell, which is indicated by saying that this plant is *leptosporangiate.* The sporangia are stalked and have a special structure, the annulus, for the distribution of spores.

This plant exemplifies well the order Filicales, the true ferns, one of the chief orders of Pteridophytes.

"SCOURING-RUSH," OR "HORSETAIL."

Equisetum arvense.

PTERIDOPHYTES; EQUISETALES; EQUISETINEÆ.

PRELIMINARY.

THIS plant is selected as a representative of a subdivision of the Pteridophytes, the *Equisetales*, in which there are about twenty-five living species, all belonging to one genus. Other species may be selected for study, but the one named will be found most often in many localities. It grows on shady hillsides, along railway tracks, and sometimes in open fields. It may be found along the banks of ponds and streams, but in such places other species of *Equisetum* are more likely to be found.

The pale reddish-yellow spore-bearing branches appear early in the spring, usually the latter part of March or April. They are straight unbranched shoots, from three to twelve inches in height, and bear cone-like structures at their tips. Near these achlorous shoots and arising from the same underground stems will be seen the branched green shoots. These become much more prominent as the spore-bearing shoots disappear. In other species than *Equisetum arvense* the spores are borne by single tall unbranched green shoots.

Good material of root-stocks and both kinds of aerial shoots should be collected and preserved, some by pressing and drying, and some, especially spore-bearing shoots, in alcohol or formalin. Fresh material, if obtainable, should be used.

LABORATORY WORK.

GROSS STRUCTURE.

I. The Spore-bearing Shoot. Observe:

1. The straight jointed stem.
2. The circle of leaves at each joint (node).
3. The structure of the node as seen when a stem is broken at that point.
4. The terminal cone, composed of small spore-bearing leaves (sporophylls) arranged in regular order.
5. Draw.

II. The Green Shoots. Observe:

1. Mode of branching.
2. Similarity in structure of the main axis and its branches to that of the stem which bears the cone.
3. Draw two or three internodes.

III. Rhizome.

Observe how the leaves and roots arise from it. Show this by a sketch.

MINUTE STRUCTURE.

I. The Aerial Stem.

Make a cross-section between the nodes of a spore-bearing shoot and of a green shoot; mount under one cover and compare as to:

1. The general outline of the cross-section.
2. The ridges and furrows along the outer surface.

3. The location of the chlorophyll-bearing cells.
4. The stomata and their location. (Compare with surface view.)
5. The location of vascular bundles.
6. Draw.

II. The Sporophylls.

Remove a few of the sporophylls, and lay in water so that they may be seen from different directions. Observe:

1. The form of the outer parts of the sporophylls.
2. The central stalk.
3. The number and position of the sporangia.
4. Draw.

Tear open some of the sporangia, mount and observe under the microscope:

5. The spores, whose outer wall forms:
6. The *elaters*. Note the position of the elaters when the spores are moist. Allow some spores to dry on a slide while watching them, and note the position and behavior of the elaters as they become dry.
7. Draw.

ANNOTATIONS.

Equisetum arvense shows at least two features not yet seen in any of the plants studied, although one of these exists in some of the true ferns. First, the spore-bearing shoot is separated from the green vegetative shoot; and secondly, the sporophylls upon this spore-bearing shoot are distinctly unlike foliage leaves, as we commonly know them, and are gathered into a compact cone-like cluster. All the chlorophyll work is done by the branched shoots, the leaves doing none and apparently serving

merely to stiffen the nodes and to protect the basal growing regions of each internode.

The stems are jointed, tubular, and ridged, the chlorophyll appearing within the ridges, and the stomata along their slopes. The stems also contain much silica which makes them gritty.

Surplus food is stored in the rhizome, and is used partially or wholly as nourishment for the sporiferous stalk early in the succeeding season.

In the groups of sporangia on the sporophyll many spores are borne. Each spore is covered as it develops by a special outer coat which cracks at maturity in a spiral fashion and so forms the elaters, not at all the morphological equivalents of elaters of liverworts. As the spore becomes dry the elaters straighten, and in doing so jerk the spores about from place to place. Becoming entangled, they may also hold several spores together for a time.

The spores produce gametophytes, each of which bears but one kind of sex-organ, i.e. is diœcious. Since elaters hold the spores in masses, one kind of sex-organ is more likely to be formed in the vicinity of the other than would be true if the spores were scattered singly.[1]

Equisetums were far more abundant and luxuriant formerly than now. Fossil remains show that during the coal ages some genera of the order were often large trees that composed a prominent part of the vegetation. These highly specialized forms have ceased to exist and are now represented only by their fossils and by their lowly

[1] If fresh spores may be had, it will be possible to study the gametophytes and sex-organs. The spores germinate quite readily and must be used soon after being gathered, else they lose their power to germinate.

kin, the genus *Equisetum* with about twenty-five living species. The species of to-day are more simple in structure than some of those of geological ages. The order is in its old age and has almost disappeared.[1]

[1] Read on Fossil Equisetums in Seward's "Fossil Plants" or other text-books that describe them.

THE "CLUB-MOSS."

Selaginella sp.

PTERIDOPHYTES; LYCOPODIALES; SELAGINELLACEÆ.

PRELIMINARY.

In the Lycopodiales, the order to which this plant belongs, there are only a few genera. These bear much general resemblance to one another, although they are quite unlike in several important details. *Selaginella* is one of the few living plants that are intermediate in certain characters between other Pteridophytes and the lowest Spermatophytes. Most of its species are found in the warmer temperate regions and the tropics, although a few inhabit the colder temperate regions. Some species are commonly grown in greenhouses, where the fruiting spikes may often be found and collected for class use. Fresh material will be much better for study, but the plant retains its characters in alcohol and formalin, and may thus be kept indefinitely for class use. If *S. rupestris* can be obtained it will be found highly satisfactory.

LABORATORY WORK.

GROSS STRUCTURE.

I. The Vegetative Body.

With a good branch as a specimen, observe:

1. The position in which the stem grew.
2. Position of leaves.
3. The number of rows of leaves, their relative size, and their distribution on the stem. Note how the size and position of leaves are adapted so that all may have sufficient exposure to light.
4. Aerial roots, coming from the stem as branches and descending to the soil. Draw.

II. The Reproductive Body.

At the tips of some branches the sporophylls form a close cluster, known also as a *spike* or a *strobilus*. Observe:

1. The number of rows of sporophylls.
2. The arrangement of the sporophylls.
3. Through some of the sporophylls, the sporangia, appearing as yellow or red dots.
4. Draw.

MINUTE STRUCTURE.

I. The Leaf.

Mount an entire leaf, and observe:

1. General form of cells in the midrib, the margin, and the body. Examine these in detail, particularly the cells of the main part of the leaf and the peculiar plastids they enclose.
2. Draw.

II. The Stem.

By means of a cross-section of the stem observe:

1. The outermost (epidermal) layer of cells, and the thick cuticle which is the outer layer of its surface walls.
2. The centrally placed vascular bundle region. Note the distribution of xylem and phloem and compare with the vascular bundle of *Pteris*.
3. Draw a sector of the section.

III. Asexual Reproduction.

Some sporophylls bear sporangia which contain many small spores; others bear sporangia in which large spores are formed. The two kinds are sometimes found in the same strobilus. Remove and mount several sporophylls, and observe:

1. The sporangium on each one. Make a drawing of a good specimen.
2. Open the walls of the sporangium and observe the spores.
3. Compare the two kinds of sporangia as to color, form, and size, and draw both kinds.
4. Determine the number of *megaspores* (large spores) produced in a sporangium.[1]
5. Mount microspores and megaspores so that both can be seen in one view by use of the low power, and make drawing showing their relative size and similarity of form.

IV. Sexual Reproduction.[2]

1. The male gametophyte. In a section through the wall of a microspore that has germinated observe:

[1] The number of microspores (small spores) produced in a sporangium is so great that it will not be possible readily to determine their number.

[2] It is very difficult to obtain sections that will show satisfactorily the gametophytes of *Selaginella*. Directions for making such sections may be found in Chamberlain's "Methods in Plant Histology," pp. 111–113. If sections of the gametophytes of *Marsilia* can be had, they will serve well in place of those of *Selaginella*. Usually it will be found much more satisfactory if there are supplied prepared sections of *Marsilia* or *Selaginella* for this work. The gametophyte development is not the same in the two genera, but the *Selaginella* outline can be readily adjusted to the study of *Marsilia*.

a. The cells formed just within the spore wall and that separate it from:

b. A centrally placed cell, which later divides, thus forming the mother-cells that in turn form the sperms.[1]

c. Draw.

2. The female gametophyte. By studying a section of a germinating megaspore observe:

a. The space enclosed by the megaspore wall partially filled at its apical end by female gametophyte tissue.

b. The basal part containing vacuoles, or granular food substances, or both.

c. The archegonia developed on the part of the gametophyte exposed by the rupture of the spore wall.

d. Draw.

In some sections it may be that eggs have been fertilized and stages in the development of the sporophyte embryo can be seen. If so, note the following stages:

e. The first division-wall of the oospore.

f. The elongation of the outermost of the two cells formed by the first division of the oospore. This elongated cell is the *suspensor* and serves to push the other cell (embryo-cell) into the female gametophyte that nourishes the embyro as it develops.

g. A specimen in which embryonic leaves, stem, and root can be distinguished.

h. A specimen in which the young sporophyte plant is emerging through the megaspore wall.

i. Draw, illustrating the various stages seen.

[1] With *Marsilia* it is comparatively easy to obtain living sperms by placing the dried sporocarps in water. After a day or two the microsporangia and spores will be pushed out of the sporocarp and the sperms will escape from the male gametophytes produced within the microspore walls.

ANNOTATIONS.

In general appearance *Selaginella* is more like higher plants than any Pteridophyte yet studied, and this general resemblance is borne out in detail in most of its structures. The stem is not so complex as in some of the true ferns, but has similar concentric vascular bundles. The horizontal stem bears four rows of leaves, those of the two uppermost rows being small and so arranged as not to shade the larger lower ones. The lower leaves are twisted on their petioles so as to expose their flat surfaces to the light.

The aerial roots serve to support the stem from which they come, and also to absorb nourishment from the earth.

In the Pteridophyte groups previously studied the asexual spores are all of one kind. In *Pteris* it was seen that any spore possessed the power of producing a gametophyte that could form both kinds of sex-organs and gametes. It was observed in that connection that a small or poorly nourished gametophyte produced antheridia and no archegonia. In those ferns that have only one kind of asexual spore (*homosporous* ferns) the question of nutrition seems to determine whether a gametophyte can produce both sex-organs. In *Selaginella*, as in all higher plants, there are two kinds of asexual spores, each of which produces a certain kind of gametophyte. The microspore upon germination produces a male gametophyte, which in turn bears the male sex-organ contain ng male gametes. The megaspore produces the female gametophyte on which

the archegonium with its egg is formed. These spores are produced in specialized sporangia on specialized sporophylls. The sporophylls are gathered into strobili or cones.

A difficulty for the beginning student in studying plants with two kinds of asexual spores (*heterosporous* plants) often arises from the fact that the gametophytes are greatly reduced in size and are almost entirely enclosed by the walls of the spores that produce them. It is usually impossible by superficial observation to determine whether the structure is an asexual spore, or a gametophyte enclosed by an old asexual spore-wall. It must always be kept clearly in mind that the spores which produce these gametophytes are neither male nor female, but asexual spores. Spores are called asexual with reference to the way in which they are formed, not with reference to what they produce when they germinate.

After fertilization has taken place, the oospore begins its germination by means of a wall that cuts it into two cells, one of which elongates and forms the suspensor. This pushes the other one down into the female gametophyte tissue, where it grows at the expense of food absorbed from the gametophyte and soon forms the embryo, which early shows the rudiments of foot, root, stem, and leaves. The latter three organs gradually break through and emerge from the female gametophyte and the plant soon becomes independent. All these processes except the last often occur before the megaspore has even escaped from the sporangium. If before the embryo emerged it had become dormant while enclosed in the female gametophyte, and the wall of the megaspo-

rangium had developed so as to form a firm covering for the gametophyte and embryo, we should have a *seed*, the characteristic structure of the next great group.[1]

It is by no means certain that seed-plants originated from ancestors like *Selaginella*. Nevertheless the resemblance between it and the great group, Angiosperms, is striking and too significant to be overlooked.

[1] Examine text illustrations of Selaginella, and also those by Miss Florence M. Lyon on "A Study of the Sporangia and Gametophytes of *Selaginella apus* and *Selaginella rupestris*," Bot. Gaz. 32 : 124 and 170.

A PINE.

Pinus Austriaca, or P. laricio.

GYMNOSPERMS; CONIFERALES; PINACEÆ.

PRELIMINARY.

In many parts of the country the only living pines are those that have been planted for ornament. Several species have been introduced in this way, and although in some localities a relatively small number of individuals are found, the number is sufficient to make the collection of materials fairly easy. The Austrian pine has two polished dark-green needle-leaves in a group. The cones in which the seeds form are ten to fifteen centimeters long and are relatively smooth.

The Scotch pine, with its leaves also in pairs, may be distinguished from the Austrian pine by its shorter leaves (eight centimeters), its shorter cones (eight centimeters) with their scales having prominent projections on the free ends, which toward the base of the cone are curved; and also by a grayish powdery coating upon the leaves.

Early during the growing season, usually in the month of May, two kinds of young cones may be distinguished. At the tip of the young shoots very small *megasporan-*

giate or *carpellate* cones may be seen appearing as small side branches. At the base of young shoots the clusters of *microsporangiate* or *staminate* cones appear.

They do not usually appear on the same young shoot as the others, and a tree usually bears many more of one kind than of the other. The staminate cones shed their *pollen* (microspores) early in the season.

Specimens of both kinds of cones should be collected at the time the staminate cones are about ripe, together with the young shoots and needle-leaves. At the same time some of the oldest carpellate cones should be collected. In the winter one-year-old and two-year-old cones, and the buds enclosing growing tips, should be collected. All collections of entire specimens should be preserved in alcohol, and the data of collecting carefully recorded. In addition to these, young cones of both kinds and also carpellate cones about a year old should be collected and preserved for sectioning of the sporangia by imbedding. Leaves and branches may be gathered at almost any time, it being best to have them fresh at the time the study is made. The resinous material is removed by putting the specimens in alcohol for at least a day or two before using them.

LABORATORY WORK.

GROSS STRUCTURE.

I. General Characters. Observe:

1. The central axis or stem; its few *main branches*, and numerous very short *dwarf branches*, each bearing:
2. A pair of slender elongated *needle-leaves*.
3. *Scale-leaves* upon the stem, about the dwarf branches, and base of needle-leaves, and covering the terminal buds.

4. Near the bases of some of the young shoots:
   a. The clusters of *staminate cones* or flowers, each composed of crowded *stamens* (microsporophylls); and at the tips of other young shoots:
   b. The very small *carpellate* cones or flowers, each composed of closely crowded carpels (megasporophylls); and on older parts of the branch:
   c. Larger, heavy, woody, carpellate cones.

II. The Stem.

On a branch eighteen inches or two feet in length observe:

1. The marks indicating the beginning and ending of each year's growth.
2. On the last year's growth, the scale-leaves.
3. Whether scale-leaves are on each year's growth.
4. The relative vigor of terminal and lateral shoots.
5. The buds at the tips of shoots.
6. The arrangement of the dwarf branches that bear the needle-leaves.

Cut across a three- or four-year-old shoot and observe:

7. The *central pith* region.
8. The outer chlorophyll-bearing *bark* region.
9. Between these the *woody* region. The annual *growth rings* indicate the age of the shoot. Sketch the cross-section.

III. The Leaves.

1. Scale-leaves. Observe:
   a. The size, form, position, and arrangement of scale-leaves on main shoots. Note the differences between scale-leaves on dwarf shoots enveloping needle-leaves and those about buds.
   b. The scars left as scale-leaves that surround the bud are dropped.
   c. Draw one or two scale-leaves of each kind.

2. Needle-leaves. Observe:
   a. How the weak bases of each pair of leaves are enclosed and stiffened by a sheath of scale-leaves.
   b. The toughness of the mature needles. Remove a pair, pull away the scale-leaves, and observe:
   c. The dwarf branch on which the needles are borne.
   d. Draw a pair of leaves upon the branch that bears them.

IV. The Cones.

1. Staminate cones. Remove from the cluster one cone, note and make sketches showing the outward appearance, the arrangement of the sporophylls that compose it, and a single microsporophyll, showing top and edge views.
2. Carpellate cones.
   a. Young cone. By use of material collected about June 1st, observe the young cones emerging as lateral branches at the tip of the young growth of shoot and needle-leaves. The separate sporophylls are not conspicuous, but may be distinguished easily. Sketch.
   b. One-year-old cone. On some one-year-old shoots may be seen cones that have grown considerably and that have changed greatly from the appearance of the very young cones.
   c. Two-year-old cones. Observe:
      i. The outer appearance and arrangement of megasporophylls or carpels.[1]
      ii. The completely sealed condition of old cones that were collected early in the spring.
      iii. Draw.

   Remove some of the sporophylls, and observe:
      iv. The general form.
      v. The seeds, and seed-wings borne upon them.
      vi. Draw.

[1] For full statement regarding the structure of the carpel, see Coulter and Chamberlain's "Seed Plants," Vol. 1 (Gymnosperms), pp. 69–77.

MINUTE STRUCTURE.

I. The Stem.

Make a transverse section of a year-old stem,[1] collected in May or June, and study the different tissues composing it as follows:

1. The pith, occupying the center of the section. Observe:
   a. The general outline of the region. In some sections will be seen portions of the pith that run outward. These lead into branches.
   b. The form and arrangement of the cells.
   c. The contents of cells; test for starch.
2. The wood (xylem), the heavy-walled tissue surrounding the pith, and separated somewhat regularly into wedge-shaped masses by the *medullary rays.*

   Select a good wedge and observe:
   a. The resin-ducts, one or two of which appear at the inner edge of the wedge. Immediately around the duct is a circle of very thin cells, the secreting layer. In each of these cells is the granular nucleus, characteristic of secreting cells in general. Surrounding the secreting layer and much more prominent is a layer of thick-walled cells, forming a *sheath.*
   b. Between the resin-ducts and the pith a few very small rounded cells with rather thick walls, the primary xylem vessels.
   c. The main bulk of wood fibers, the *tracheids.* In the wood observe:
   i. The form and arrangement of the *tracheids.*
   ii. Their emptiness.
3. In the thinnest part of the specimens search for sections

[1] Sections may be made of stems by using material that has been preserved in alcohol for at least a few days, then soaked in a mixture of alcohol and glycerin. Such sections may be used directly or may be rendered somewhat more satisfactory by use of differential stains.

of the *bordered pits*, characteristic of the wood of the group of plants to which the pines belong.[1]

4. Outside the xylem, a thin layer of cambium tissue, seen only in sections cut with extreme care from stems collected during the growing season.
5. The phloem, the whitish tissues outside the xylem and cambium, composed of:
   a. Angular, whitish cells making up the greater part, the *sieve*-cells.[2]

      Compare the shape of active sieve-cells next the cambium and those near the outside of the phloem, which have become functionless with age.

   b. Near the periphery of the sieve-tissue an interrupted row of cells with brown or yellow contents in which are strongly refringent crystals. Near the cambium a similar row of cells, larger and rounder than the sieve-cells and with colorless or slightly yellowish homogeneous contents, in which a small crystal or two may sometimes be seen. These two broken rows of cells are the *phloem parenchyma*.[3]
6. The cortical parenchyma, lying just outside the phloem. Observe.
   a. The shape, size, and arrangement of the cells. Compare with the pith parenchyma in these respects.
   b. The contents of cells, including the distribution of chlorophyll.

[1] For a clear idea regarding the structure of the bordered pits, as well as for a knowledge of the structure and relations of the other parts of the wood of the pine, see Strasburger's "Botanisches Practicum," Coulter and Chamberlain's "Gymnosperms," and other text-books.

[2] So called because the radial walls of these cells are perforated by clusters of very fine pits, the *sieve*-plates; they occupy the same relative position as the bordered pits of the tracheids.

[3] These two tissues of the phloem can be well demonstrated by means of differential stains.

   c. The resin-ducts. Compare their structure with that of the ducts in the xylem.

7. By use of a very thin section study the medullary rays, observing:
   a. The rays extending from the pith to the cortical parenchyma.
   b. The shape of the cells in the xylem and the gradual transition into the cortical parenchyma.
   c. The cell contents.
8. The outermost part of the stem is composed of the bases of the scale-leaves. In one leaf-base observe:
   a. An inner layer of very thin-walled irregular cells.
   b. An outer layer of one or two rows of large cells upon which is a single row of epidermal cells. Observe:
      i. The thickening of the outer epidermal wall, and
      ii. The continuous outer layer of this wall, the *cuticle.*
9. Make a diagram of the entire cross section and label the various regions.
10. Draw in detail a narrow strip including all kinds of stem tissues from pith to epidermis.
11. Make a thin longitudinal radial section of a year-old stem, and identify by their arrangement the various kinds of tissues seen in the transverse section, and study the difference in shape of cells in this section.
12. Draw in detail small regions which show structures not seen in cross-section.

Make a thin tangential section through the wood. Observe especially:

13. Ends of medullary rays.
   a. The number of rows of cells in thickness and height of each ray.
   b. The thin parts of the walls corresponding to the pits.
   c. Draw, including a few adjacent tracheids.

14. Sections running in various directions through bordered pits.
15. The very tapering ends of tracheids.

II. THE LEAF.

Make a cross-section of the needle-leaf, mount and note the following regions:

1. The outer heavy-walled epidermal and strengthening region.
2. The mesophyll region, made conspicuous by the presence of chlorophyll.
3. The vascular bundle region, composed of light-colored cells and surrounded by a distinct row of cells, the *bundle-sheath*.
4. Make a diagram showing the form of the cross-section, and the relative position and extent of each region.

Study the details of each region as follows:

5. Epidermis.
   a. The thick cuticle.
   b. The epidermal cells, their very thick walls and the peculiar thickening within the cells.
   c. At somewhat regular intervals the *stomata*, each *stoma* consisting of:
      i. An outer chamber which appears as a depression in the cuticle and epidermal layer.
      ii. An inner chamber lying within the chlorophyllose tissue immediately below the outer chamber.
      iii. A narrow opening connecting the two chambers.
      iv. At the sides of the outer chamber are two prominent epidermal cells, and immediately beneath these are:
      v. Two smaller *guard-cells* distinguishable by containing chlorophyll.
6. The incomplete layer of cells immediately below the epidermis, the *sclerenchyma* or *hypoderma*. Observe:

a. The number of rows of cells in thickness in different parts of the section, and their compactness.

b. The especial adaptation for strengthening the leaf at its angles.

c. The small circular (in section) cell cavity, and the heavy walls with pore-pits.

7. The mesophyll.

a. The shape of the cells, the average number of rows between the hypoderma and the bundle-sheath.

b. The infoldings of the wall, dividing the cavity into recesses. Observe the position of the most prominent of these infoldings in the outermost row of mesophyll-cells. Observe occasionally (usually near a stomatal cavity) branched cells.

c. In fresh specimens the abundant chlorophyll.

d. The resin-ducts; compare their structure with that of the ducts in the stem. Notice the thick walls of the sheath-cells.

8. The vascular bundle region.

a. The bundle-sheath; shape and contents of the cells.

b. The two masses of small cells, the two *vascular bundles*. Each bundle is distinctly divided into a xylem and phloem area. A partially developed resin-duct sometimes appears in the xylem.

c. Surrounding the bundles, the *parenchyma*, some of which may form radial rows running through the bundles as medullary rays.

d. Make a diagram of the section and draw a narrow strip across it, showing in detail each kind of tissue.

III. THE MICROSPOROPHYLL.

From a cone that was collected just before the pollen-grains were shed, remove some of the stamens and observe:

1. Their general form.

2. The parts composing each stamen, the short stalk (the *filament*), the two long *sporangia* that make up almost the entire body, and the flat extension at the outer part. Tear open a few sporangia, and study the *microspores* (*pollen-grains*), observing:
3. The central cell from the wall of which two lateral bladdery outgrowths, the "wings," have developed.
4. Within the central cell the granular cytoplasm and usually one or two *nuclei*.[1]
5. Draw a microspore.
6. Observe the structure of a small piece of the sporangium wall and make a sketch showing it.

IV. THE MEGASPOROPHYLL.[2]

From a one-year-old cone remove some of the sporophylls and observe:

1. On each sporophyll one or two elevations on its upper side near the *axil*, between it and the axis of the cone. These are the *megasporangia*, or *ovules*.
2. The open end of the ovule extending downward.
3. By means of prepared longitudinal sections of the ovule cut perpendicular to the flat surface of the carpel, study the structure of the ovule, observing the following parts:
   a. The outer covering (the *integument*) extending downward about the opening.

[1] If there are two nuclei, it is evident that the microspore has begun to germinate to produce the male gametophyte and male cells. Often one of the new cells formed through division of the spore nucleus will be seen to be a lenticular one rather closely pressed against one side of the microspore wall. The nucleus of the other cell may lie anywhere in the larger mass of cytoplasm.

[2] The material most needed will be found in cones collected at the time they are about a year old. If there is at hand a good supply of entire cones and separate sporophylls collected at intervals of ten days or two weeks during spring, so that they are suitable for sectioning to show different stages of development, microtome sections should be prepared. See Chamberlain's "Methods in Plant Histology," pp. 119–121.

b. The opening, the *micropyle.*

c. The tissue enclosed by the integument, the *nucellus.*

d. Within the nucellus the large rounded cell, the *megaspore,* or the *embryo-sac* containing female *gametophyte.*[1]

In fully developed female gametophytes observe:

e. Their general form at their micropylar ends.

f. The archegonia. Study the archegonia in detail, observing:

i. The large base—the egg—and the prominent nucleus it contains.

ii. The neck opening toward the micropyle.

g. In some cases may be seen pollen-grains that have been deposited on the nucellus, and from which pollen-tubes have grown toward the necks of the archegonia for the purpose of carrying the male cells to the egg.[2] Observe especially the tortuous course of the pollen-tube.

h. In older ovules the young embryo of the sporophyte may be seen. Note its form and structure; also how it has used up adjacent gametophyte tissue as food.

i. From fully developed ovules (*seeds*) dissect out the embryo and note *root*, *stem*, and *cotyledons* (seed-leaves), noting also how completely it is surrounded by the female gametophyte tissue. Identify in the seed the various parts of the ovule.

j. Observe the wing on fully ripened seeds. Drop one from a height of a few feet, and time its fall. Then tear away

[1] In most cases the student will find no megaspore within the sporangium, since the megaspore will have germinated to produce the embryo-sac and female gametophyte. These are enclosed by the nucellar tissue. In prepared sections they are often so contracted as to be pulled away from the surrounding nucellar tissue.

[2] Since the male gametophyte and male cells are at first entirely enclosed by the wall of the former microspore, in order to bring the male cells into the vicinity of the female gamete (egg), the entire microspore with its contents is carried by the wind to the nucellus of the sporangium. This transfer of microspores is called *pollination.* When the spore is located on the nucellus the processes of *fertilization* may begin.

the wing and time the fall of the seed alone. What would be the effect in a wind?

k. Make a drawing illustrating the carpel, and the ovule with its various parts as outlined above.

ANNOTATIONS.

The pine raises a strong tall stem above the ground, thus better exposing its leaves to the light. This stem also serves better to expose the flowers so that pollination may be effected and that ripened seeds may be distributed. This stem habit is made possible through the extensive development of mechanical and supporting tissues.

The stem by means of its terminal buds may continue its growth in length, and also may continue its growth in diameter by means of the growth cylinder—the cambium layer—that lies between the xylem and phloem. The difference in the size and form of the cells added to the xylem at different times in the growing season gives rise to markings or annual growth rings that indicate the age of the stem.

In the details of its structure the stem is somewhat complex. In its central part is a pith region composed of ordinary parenchyma cells. In the innermost region of the xylem are a few greatly elongated, tubular cells, *tracheæ*, which are not found in the secondary wood of pines, but are of especial interest since they appear abundantly in the wood of the next and highest group, the Angiosperms. In the Gymnosperms the bulk of the wood is almost exclusively made up of tracheids. In the development of the vascular tissue the cells become greatly elongated, and in tracheæ most of the end walls of the cells

disappear, leaving the vessels as continuous tubes. In tracheids the end walls do not disappear. As the tracheids in the pines and their kin develop, the lateral walls, originally thin and plain, thicken irregularly, a part of the thickening on each side of the primary wall growing away from it to form the "border" of the small spot that remains thin, the whole constituting the "bordered pit." Usually the primary wall remains as a membrane separating the two cells. Should it be destroyed, there would be free communication between the contiguous cells.

Outside the xylem region is the cambium tissue, composed of a few layers of thin-walled active cells from which during the growing season new cells are constantly formed by division. In the phloem just outside the cambium the leading tissue-element is the sieve-cells. These are elongated cells, the side and end walls of which have become perforated, thereby forming "sieve-plates," through which food may pass. The "sieve-cells" are used largely as transporting and temporary storage regions for foods. Outside the phloem region the layers of living and dead cortex are formed.

The scale-leaves are entirely protective, while the foliage work is almost exclusively done by the needle-leaves. The epidermis and sclerenchyma of the needle-leaves are especially thick-walled and serve to give rigidity to the leaves, and to protect the chlorophyll-bearing tissues against rapid changes in temperature and too great loss of water. The sunken position of the guard-cells secures them against stoppage which would hinder the entrance of necessary gases.

The needle-leaves are borne upon dwarf branches that may be seen when the sheathing scale-leaves are removed. It is to be noticed that the vascular bundles of all the needle-leaves of a pair or group borne on the same dwarf branch have their xylem portions facing a common center, while their phloem portions are peripheral, as would be true in an ordinary branch from the stem. The imbedding of the vascular bundles in a group of colorless tissue surrounded by a sheath is common among the pines and their allies. Poorly developed resin-ducts are occasionally found in the xylem of leaf-bundles, although it has been denied by some writers.

In comparing the reproduction of the pines with that of the plants already studied we find advances of much interest. In the Bryophytes and in the lower Pteridophytes the asexual spores upon germination develop relatively prominent structures upon which sex-organs eventually develop. These sex-organs produce gametes and sexual spores from which grow sporophytes, upon which the asexual spores are produced in their turn. In the highest Pteridophytes the asexual spores are unlike in size, produce unlike gametophytes, and after germination retain the gametophytes within their walls. Fertilization occurs even while the female gametophyte is within the old cracked megaspore wall. In *Selaginella* the embryo sporophyte not only begins its development within the female gametophyte while this is enveloped by the ruptured spore-wall, but often while the megaspore still lies unshed, enclosed in the sporangium which produced it. Furthermore, in these highest Pteridophytes the sporophylls are collected into distinct cones.

In the pines the sporophylls are likewise gathered into cones, but the two kinds of cones are unlike, due to the difference in the sporophylls that compose them. The megasporangia (ovules) are produced upon the megasporophylls (carpels) and the microsporangia (pollen-sacs) upon microsporophylls (stamens). The mega-sporangium does not open and therefore the megaspore is never shed, but germinates, as often in *Selaginella*, within the tissues of the sporangium (ovule). There it produces a female gametophyte which remains enclosed within it, because it does not grow large enough to rupture the spore-wall, yet the gametophyte bears distinct archegonia. Since these archegonia are not exposed, the male gametes cannot gain entrance to them by swimming in water as heretofore, even were such a medium present.

The microspore (pollen-grain) may begin its germination before it leaves the sporangium or afterward. Since these pollen-grains are carried in quantity by the wind, one or more of them may be deposited on the nucellus of the ovule. From the inner wall of those favorably deposited there develops a tube that grows parasitically through the sporangium and spore-wall to an archegonium on the female gametophyte. The male cells, which may have been formed before or after the tube began to grow, migrate to the end of the tube which passes to the neck of the archegonium. At this time the end of the tube opens and allows the male cells to escape. One male cell unites with the egg, thus producing the oospore.[1]

[1] It is noteworthy that in several other Gymnosperms ciliated sperms have been found. Such structures suggest the existence formerly of a watery medium enabling them to pass by swimming from the male gametophyte to the egg.

It is important to observe also the long time required to effect the development of the pollen-tube and the subsequent fertilization, for about a year elapses between the transfer of the microspore to the megasporangium before fertilization actually occurs. More highly specialized plants, as some Angiosperms, grow pollen-tubes many times as long as those of the pine in an almost incredibly short time, often in the course of a few hours.

The oospore germinates and produces the embryo sporophyte. As this goes on, the whole sporangium grows, and by the time the rudimentary root, stem, and leaves are formed the outer parts of the ovule have become dry and hard, forming the testa, and the embryo itself has entered upon a dormant period. In this state the whole structure constitutes a *seed.*[1]

As the ovule grows and ripens the upper surface of the carpel becomes separated from the main body, and remains attached to the seed as the wing.

In the spring or early summer succeeding the ripening of the seed, by the drying and warping of the carpels, the cones open and the seeds are shaken out by winds which, because of the buoyancy of the wings, carry away the seeds to some distance from the parent tree. Under favorable conditions the embryo resumes its growth, emerges from the seed-coat, and begins to establish itself as a new (pine-plant) individual.

[1] It will be interesting in this connection to review from *Coleochæte* to *Pinus* the effect produced upon adjacent tissues by the act of fertilization. See also "The Origin of Gymnosperms and the Seed Habit," by John M. Coulter, Bot. Gaz. **26** : 153–168, and "Origin of the Leafy Sporophyte," by John M. Coulter, Bot. Gaz. **28** : 46–59.

WAKE-ROBIN.

Trillium sp.

ANGIOSPERMS; MONOCOTYLEDONS; LILIACEÆ.

PRELIMINARY.

THE various species of *Trillium* may be found flowering in rich woods in early spring. The plants are easily distinguished from others by the straight naked stems that are fifteen to thirty centimeters in height, the circle of three broad net-veined leaves, and the single terminal flower with three floral organs in each cycle. The flowers vary considerably in the different species, but any of these species will serve well for this study.[1]

If the laboratory study is not to be made at the time Trilliums are flowering, a good supply should be preserved both dry and in alcohol or formalin for class work.

[1] In case material for work with *Trillium* cannot be had, in place of it may be used the hyacinth, tulip, lily (*Lilium*), wild onion (*Allium*), or any other such plant belonging to the Monocotyledons, the group to which *Trillium* belongs. In case one of these is used, the outline given for *Trillium* will serve to guide the study in a general way.

LABORATORY WORK.

GROSS STRUCTURE.

I. General Characters. Observe:

1. The main axis consisting of a thickened, horizontal underground stem, the *rhizome* or *root-stalk*, and a single vertical branch, the *aerial stem*, bearing a terminal *flower*.
2. The root-stalk, bearing as lateral appendages the roots and modified leaves in the form of broad membranous scales.
3. The aerial stem, bearing as lateral appendages a whorl of three foliage leaves, and the parts of the flower, in five whorls.

II. The Roots. Observe:

1. Their arrangement on the root-stalk.
2. The absence of *branching*.
3. The surface, especially the transverse wrinkles on older parts. What is the significance of the wrinkles?

If quite fresh specimens are used, it may be possible to see:

4. The root-hairs.

III. The Root-stalk (Rhizome). Observe:

1. Its *shape* and *thickness*.
2. The succession of *nodes* and *internodes*.
   a. Their number in an unbroken root-stalk.
   b. The *scars* of former branches, and the varying number of intervening nodes.
   c. The *irregular growth* of the internodes.
3. The apical bud and its protecting scales.
4. Sketch a piece of the root-stalk with some of the roots growing upon it.

IV. The Branch (aerial stem).

1. The absence of nodes below the whorl of leaves.
2. The smoothness of the surface.

V. THE LEAVES.

1. The scale-leaves of the root-stalk.
   a. The bases of decayed scales at each node.
   b. Younger ones sheathing the apex of the root-stalk, the bud, and base of the aerial branch.
2. The foliage leaves.
   a. Their *number*, *arrangement*, and *shape*.
   b. The outline of the base, margin, and apex.
   c. The leaf-stalk or *petiole* (not present in all species).
   d. The system of veining.
3. Draw different forms of scales and one foliage leaf.

VI. THE FLOWER. Observe:

1. The parts of the flower.
   a. The lower cycle of green leaves, the *calyx*, each member of which is a *sepal*.
   b. The cycle of colored leaves above the calyx, the *corolla*, each member of which is a *petal*.
   c. The two cycles of organs next above the corolla, each member of which is a microsporophyll or *stamen*. In one stamen observe:
      i. The stalked base, the *filament*.
      ii. The enlarged tip, the *anther*, showing on its inner face four swellings, the microsporangia. In anthers that have opened, masses of microspores (pollen-grains) may usually be seen.
   d. The innermost organ of the flower, made up of three megasporophylls or *carpels* united into one *pistil*. Each pistil is composed of:
      i. An enlarged base, the *ovary*, in which megasporangia or ovules are formed. Tear open the ovary and locate the ovules.
      ii. A short tapering portion immediately above the ovary, the *style*.

iii. A roughened or hairy surface on the inner and upper part of each style, the *stigma*. Note whether any microspores (pollen-grains) are attached to the stigma.

2. That the parts of the flower arise from the end of a stem which is broadened to form the *receptacle*.
3. That all other parts are placed below the pistil, that is, they are *hypogynous*.
4. That each cycle is made up of a definite number of organs.
5. That the members of one cycle of floral organs alternate in position with the members of the succeeding cycle.
6. Sketch an entire flower, then one member from each set of organs that compose it.

MINUTE STRUCTURE.

I. The Root.

In a central longitudinal section through a root-tip observe the following regions:[1]

1. The outer looser cells and the inner more compact tissues forming the root-cap. This is disconnected from the root except at the foremost portion.
2. In the center of the section and immediately under the end of the root-cap, a group of small angular cells, the *primary meristem*, corresponding to the apical cell in the fern-root. These constitute the region of most active cell-formation.
3. Originating in the primary meristem are regions that finally form the permanent tissues of the root. They are:
   a. The *dermatogen*, an outer layer of cells on the root proper, beneath the root-cap. This layer later becomes the epidermis, though it is not easy to distinguish it as such, since it is probably a transient structure in the root.

[1] As it is difficult to secure uninjured tips of *Trillium*, an onion partly submerged in water for a few days will supply substitutes that are even better.

b. The central cylindrical mass of cells, the *plerome,* that finally becomes the *fibrovascular bundle region* or the *stele.*

c. Between the dermatogen and plerome is the *periblem,* from which the *cortex* is finally developed.

If the material is favorable, observe:

4. The root-hairs. Observe on what part of the root they are borne, also their relation to the epidermal cells.
5. Diagram the regions observed.
6. Make a transverse section of the root a litttle way back from the tip, and identify the permanent regions mentioned in the study of the longitudinal section.
7. Diagram the transverse section.

II. The Apical Bud of the Rhizome.

Divide the tip longitudinally and on the cut surface observe:

1. The shape.
2. The sheathing membranous scales.
3. Beneath the scales the small growing point of the stem. On this may sometimes be seen rudimentary scales.
4. In some such sections one may also see the base of rudimentary branches.
5. Diagram the section.

III. The Aerial Stem.[1]

Make a transverse section and observe:

1. The single row of epidermal cells. Note the form of the cells and the thickness of their walls.
2. The large loosely arranged tissue with intercellular spaces, the *parenchyma.*
   a. The shape of the cells.
   b. Relative thickness of the walls.
   c. Intercellular spaces.

[1] It may be found advisable to use instead of the section of a *Trillium* stem that of corn (*Zea mais*) or some other Monocotyledon.

3. The vascular bundle region.
   a. The irregular *bundle-sheath* surrounding the entire region.
   b. Groups of conducting tissue distributed through the region, the vascular bundles. Note their distribution and approximate number. Each so-called bundle is really a pair of strands, being composed of two independent parts as follows:
      (1) The *phloem* strand, the outer part of the bundle, consisting of angular, thin-walled cells of various sizes. The larger cells are the sieve-cells through which most of the manufactured foods are thought to be transported.
      (2) The *xylem* strand, consisting of very thick-walled cells of various sizes. In a young stem this tissue is less abundant than the phloem, while in old stems it is more abundant. It is closely associated with the fibrous tissue that more or less invests the bundle. In very young bundles between the phloem and the xylem is a growing or meristem tissue known as the *cambium*.[1]
4. Draw a portion of the entire cross-section in which the structural elements mentioned above are shown.

IV. The Leaf.

Carefully peel off and mount epidermis from both surfaces of the leaf and observe:

1. The form of epidermal cells.
2. The stomata. Each stoma consists of:
   a. Two crescentic *guard-cells*, and

[1] In Monocotyledons all of this tissue, ceasing to divide sooner or later, becomes changed into xylem or phloem, thus producing a so-called "closed" bundle, while in Dicotyledons the persistent cambium makes possible a constant increase in diameter, the bundle being therefore "open."

b. The *stomatal slit*, that extends between the guard-cells and below the epidermis expands into the *stomatal cavity*. Observe whether stomata appear on both leaf surfaces.

3. Draw small regions from epidermis of both surfaces. Make a very thin transverse section of the leaf,[1] and observe:
4. The epidermal cells on both edges. Compare with the surface view.
5. Stomata. Find in the thinnest part of the preparation a section truly transverse to the guard-cells and compare with surface view. Observe the stomatal cavity between and below the guard-cells, and note its relation to:
6. The mesophyll tissue. In this region observe:
   a. The *palisade* mesophyll of compact columnar cells with ends outward.
   b. The *spongy* or loosely arranged mesophyll below the palisade tissue.
7. Cross-section of veins of the leaf enclosed by the mesophyll. Identify, from comparison with the stem, the tissues in the vein.
8. Draw a part of the section.

V. REPRODUCTION.

1. The stamen, microsporangia, and microspores (pollen).

In a cross-section of a young anther observe:

a. The four sporangià in which are spores in process of development.[2]

In a cross-section of a ripe anther observe:

[1] This will be far more satisfactory if made with a microtome.

[2] By means of material ranging in age from that of very young flower-buds to buds nearly ready to open, it is possible to make out an interesting and instructive series in the process of spore development. Still younger buds will show interesting stages in the development of the sporophylls.

b. That the four sporangia are ready to open in pairs, thus forming two *pollen-sacs.*

c. The thinness of the sporangium wall, and the place especially formed for opening the anther. The act of opening the sporangia is known as *dehiscence.*

d. The microspores (pollen-grains).

e. Diagram the section.

2. The formation of male gametes. In many cases the microspores will have germinated before they have left the anther. In germination the spore nucleus divides, thus forming a so-called *generative* nucleus and a *tube* nucleus. The latter is associated with the development of a pollen-tube. The generative nucleus finally divides, thus forming two male gametes. It is the rule for this last division not to occur until after the pollen-grain has left the anther. The results of the first division may often be observed within the walls of microspores still in the anther.

3. The carpels, megasporangia (ovules), and megaspores. By means of cross-section of the ovary[1] observe:

a. Ovules that appear as somewhat oval bodies attached by their bases to the central axis of the ovary. In *Trillium* the ovules are curved, having their tips turned toward their bases and also toward the central axis of the ovary. Selecting one good ovule, observe:

i. The outer covering of the ovule, the *integuments.*

ii. The opening between the ends of the integuments, the *micropyle.*

iii. The tissue of the ovule beneath the integuments, the *nucellus.*

iv. Within the nucellus the single large *megaspore*, or the *embryo-sac* that has developed from it.

v. Diagram the section.

[1] A good set of permanent serial sections of the ovules illustrating developmental stages should be at hand.

4. The embryo-sac and female gametophyte. From the megaspore that is formed within the nucellus of the ovule (megasporangium) the embryo-sac with the contained female gametophyte develops. When the spore first begins to germinate its nucleus divides and its wall enlarges. Nourishment is absorbed from adjacent tissues. Of the two nuclei formed by the first division, one passes to each end of the embryo-sac. The two nuclei divide into four, the four into eight, four of these being placed at each end of the embryo-sac. One from each end then passes to the central part of the sac, and these two unite, thus forming the primary endosperm nucleus. Of the three cells remaining nearest to the micropyle one is the *egg* or *oosphere*, and the other two are *synergids* (helpers). At the opposite end of the embryo-sac are the three *antipodal* cells. By the time these structures are developed the embryo-sac has enlarged sufficiently to occupy a considerable part of the ovule.

By means of sections of ovules within ovaries of various ages, locate and study the various stages in the development of the female gametophyte. The following stages should be observed:

a. The relatively large cell, the *megaspore*. Observe its prominent nucleus.

b. The embryo-sac, with two nuclei. Observe the change in form in the old megaspore wall, now the embryo-sac, and the positions of the nuclei. (It is possible in many such preparations to see the nuclei in process of division.)

c. The embryo-sac with four nuclei.

d. The embryo-sac with eight nuclei.

e. Nuclei from each end (polar nuclei) uniting to form *primary endosperm nucleus*.

f. The completed female gametophyte consisting of seven nuclei, one of which is the egg ready for fertilization.

g. Make drawings illustrating the above stages.

5. The oospore and embryo sporophyte. The microspores are carried to the stigma, and from them pollen-tubes grow down through the style and ovary, and into the micropyle of the ovule. As the tube pushes its way through the nucellus into the micropylar end of the embryo-sac,[1] the male gametes migrate to the end. Arrived here the tip of the tube opens, the male gametes pass out and one of them unites with the egg, thus producing the oospore.[2]

By means of sections similar to those used in 4, except that they are made from slightly older ovules, observe:

1. The oospore. Note whether the synergids are present, and whether the primary endosperm nucleus has begun to divide to form the endosperm.
2. A stage in which the oospore has divided to form the embryo. Note the suspensor cell that attaches the embryo to the micropylar end of the sac.
3. A stage in which the suspensor has become considerably elongated, thus pushing the embryo proper well into the embryo-sac. Note the condition of the endosperm calls at this time.
4. In a practically mature seed observe the much larger embryo about which the endosperm cells are closely packed.
5. Draw, illustrating the above stages.

By use of Gray's "Manual of Botany" or Britton's "Flora

[1] It has been shown by different investigators that in several Angiosperms of rather low rank the pollen-tubes may pass through the basal (*chalazal*) end of the ovule and then traverse the length of the ovule to its nucellar end, thence into the embryo-sac in order to effect fertilization. Such a condition is known as *chalazogamy*.

[2] The research work of the past few years indicates that double fertilization is not uncommon and is probably the rule in Angiosperms. It has been shown in many plants that one of the male cells unites with the egg, while the other passes down to the primary endosperm nucleus and unites with it.

of the Northeastern States and Canada" ascertain how one not knowing the generic name of this plant would discover the name and determine its classification. Determine for yourself the specific name of the plant you have studied.

ANNOTATIONS.

In its superficial appearance *Trillium* is not a good representative of the Monocotyledons. Most Monocotyledons have parallel-veined leaves with sheathing bases, but in this particular Trilliums are quite like the Dicotyledons. In flower and stem, however, it is a typical Monocotyledon.

In reproductive structures this plant shows a distinct advance over the pine, in that there is here a true "flower," i.e. groups of conspicuously colored leaves associated with the sporophylls. The calyx in flowers is usually protective and the corolla generally supposed to be a device for attraction of insects, though there are many cases where the parts do not perform these functions. The calyx or even foliage leaves may do the work of attraction. The ovules (megasporangia) are entirely enclosed by the carpels, and the microspores in pollination are placed upon the specially prepared surface of the carpel (stigma) instead of directly upon the nucellus as in the pines. This necessitates much greater elongation of the pollen-tube, which takes place in much less time. In the pine the development of the pollen-tube is accomplished in a period of twelve or thirteen months, while in *Trillium* a very much greater distance is traversed in a day or two, possibly in a few hours.

In the pine the male gametophyte is very greatly

reduced, but in Angiosperms the reduction is greater, the male gametophyte consisting merely of one tube-cell and two male cells. These may form before the microspore has left the microsporangium.

The megaspore is formed within the nucellus of the ovule as in the Gymnosperms, but its germination differs somewhat. The germination of the megaspore results in the formation of a seven-nucleate female gametophyte consisting of three antipodal nuclei, the primary endosperm nucleus, and the egg apparatus consisting of an egg and two synergids.[1] Fertilization of the egg then occurs, forming the oospore.

The peculiar phenomenon of double fertilization, already proven to exist in many plants and probable for others, offers problems difficult to solve. Heretofore it has been customary to consider the endosperm as a delayed development of the female gametophyte. The phenomenon of double fertilization suggests the possibility of two embryos formed within the embryo-sac, the one developing normally into the embryo plantlet, while the other becomes the endosperm and serves to nourish its twin. Further researches may give light upon this question.

By continuous divisions transverse to the long axis of the embryo-sac, the oospore develops the several-celled suspensor and the cell or cells known as the embryo proper. As the latter grows, various parts are differentiated and with the simultaneous growth of the ovule the ripened seed is formed. After a period of rest this

[1] The exact correspondence of these various structures to those in Gymnosperms and Pteridophytes has not yet been determined.

seed may "germinate" and produce a new *Trillium* plant.

The root-stock is a storage region for surplus foods and is a device for tiding over unfavorable seasons by retreating underground.

In the aerial stem a notable feature is the arrangement and structure of the vascular bundles. While they are not so well developed as in some other Monocotyledons (grasses, corn, oats, etc.), they show an indefinite distribution, and the closed bundle is typical of the group. Few Monocotyledons increase in thickness by cambial activity, as do the pines. When such a cambium is formed, it does not increase the radial dimensions of the xylem and phloem already formed, but gives rise by tangential division to tissues which become new, isolated bundles and parenchymatous ground tissue between them.

BUTTERCUP.

Ranunculus sp.

SPERMATOPHYTES; ANGIOSPERMS; RANUNCULACEÆ.

PRELIMINARY.

DURING spring, summer, and early autumn various species of *Ranunculus* are fairly abundant, especially along fence-rows in low grounds and in and about woods. Several species are sprawling and resemble the strawberry plant. The flowers of some of the species are formed in water, but those are undesirable for this study. If the plant is not to be studied at the time it is in flower, it may easily be preserved in sufficient quantity to serve for classes of considerable size. *Caltha* will serve as an excellent substitute for *Ranunculus*, or any other relatively simple Dicotyledonous plant may be used.

LABORATORY WORK.

GROSS STRUCTURE. Compare with *Trillium*.

I. STEM.

Is the main stem underground? If so, compare:

1. Form and size.
2. Direction of growth.
3. Branching.
4. Buds and origin of roots.

If all or some of the stem is aerial, compare with the aerial stem of *Trillium* as to:

5. Form and size.
6. Position.
7. Nodes and internodes.
8. Branching.

II. ROOTS. Compare with *Trillium* as to:

1. General appearance.
2. Branching.
3. Number.

III. LEAVES. Compare with *Trillium* as to:

1. Position of the stem.
2. Form, size, and number.
3. Division into two regions, the expanded leaf-blade, or *lamina*, and the leaf-stalk, or *petiole*.
4. Veining.
5. The leaf margin.

IV. THE FLOWER. Compare with *Trillium* as to:

1. The distribution of flowers over the stem.
2. Floral organs present.
3. Number and arrangement of organs with reference to organs of other sets.
4. Note that in *Ranunculus* the many carpels are separate, each forming a simple pistil.

V. DRAW, showing general characters of roots, stem, leaves, and flowers.

MINUTE STRUCTURE.

I. THE STEM.

Make a cross-section of the stem [1] and examine, observing:

1. The peripheral region or cortex.
   a. Outermost protecting layer (epidermis).
   b. Surface hairs and where they arise.

[1] This stem may be readily sectioned free-hand.

c. Loose arrangement of the cortical parenchyma, with intercellular spaces.

d. Presence of chlorophyll in some cells.

2. The pith region, sometimes hollow, occupying the central axis of the stem.

   a. Size and form of the cells.

   b. Intercellular spaces.

   c. Relative extent of pith area.

3. The vascular bundle region lying between pith and cortex.

   a. Distribution of the bundles.

   b. Parts of a bundle pair.

      i. Phloem, just within the cortex. Observe the extent of each phloem strand, and the way in which the phloem cells gradually grade into the

      ii. Cambium layer, composed of small thin-walled rectangular cambium cells. These actively growing cells produce new tissues from their outer and inner faces throughout the growing season.

      iii. Xylem, composed of cells whose peculiar thickenings can only be seen in longitudinal section. In the central part of an entire section will be seen the xylem ring, outside of which is the cambium ring that is in turn surrounded by the phloem ring. Examine sections of both young and old stems to see the differences in the amounts of xylem and phloem present and the way in which they are crowded together.

4. Diagram the regions of the entire cross-section and illustrate in detail the tissues composing the older stem.

II. The Leaf.

If satisfactory results were obtained in a study of the leaf of *Trillium*, the study may here be omitted. Otherwise use the leaf outline given under that plant.

III. The Flowers.

By using specially prepared slides, make a careful study and comparison with similar structures in *Trillium* as follows:

1. The development of the microspores.
2. The first stages in the germination of the microspores.
3. The development of the megaspore.
4. The germination of the megaspore and production of the female gametophyte.
5. The development of the sporophyte embryo.

IV. Classification.

By consulting Gray's or Britton's Manual used in connection with *Trillium:*

1. Trace in the key to genera in the family *Ranunculaceæ*[1] the genus *Ranunculus*.
2. Determine the species of *Ranunculus* that you have studied.

ANNOTATIONS.

This plant serves as an illustration of the group of Angiosperms known as Dicotyledons, and offers some comparisons with the Monocotyledon last studied. The leaves are petioled, net-veined, and "open" at the margin; i.e. the veins end in the margin of the leaf, and are not parallel and ending at the tip of the leaf as in the closed Monocotyledon leaves. It must be borne in mind that in the veining *Trillium* is not like most Monocotyledons. In that feature the corn plant or lily affords better illustration of the group characteristics.

The stem of *Ranunculus* has its vascular bundles so distributed as to form a hollow cylinder, all the xylem strands being next the pith, the phloem strands next the cortex, and the cambium strands between the two.

[1] For any terms unknown, see glossary in either book cited.

Such an arrangement makes possible the increase in diameter of Dicotyledonous plants throughout the growing season. In perennial trees or shrubs this increase takes place annually, as is shown by the so-called "annual rings." The strong supporting shafts of our trees are due chiefly to the great development of the xylem bundles. In Dicotyledons underground stems of all kinds are less common than in Monocotyledons; while distinctly fibrous roots, and tap-roots with secondary root systems, are the usual subterranean organs.

The flower of *Ranunculus* is a relatively simple one. The carpels are numerous and separate, each carpel here forming a separate pistil. The stamens are numerous and spirally arranged. Numerous carpels and stamens, and spiral arrangement of floral organs, are characteristic of the simpler Dicotyledons. The placing of the other floral organs below the ovary (hypogynous arrangement) is also indicative of the lower members of the group.

The classification of *Ranunculus* in the manual should be done with the idea of learning how to study the classification of plants rather than with the idea that an extensive work in classification is to be done in this course.[1]

[1] See "A contribution to life-history of Ranunculus," by John M. Coulter, Bot. Gaz. **25**: 73–88.

SHEPHERD'S-PURSE.[1]

Capsella bursa-pastoris.

SPERMATOPHYTES; ANGIOSPERMS; CRUCIFERÆ.

PRELIMINARY.

The plant is of European origin, but has become abundant in this country and elsewhere, being one of those vigorous foreign species that hasten to take possession of any cleared or cultivated land. It is found everywhere around dwellings, and in fields and waste grounds. It has not only the advantage of universal distribution, but also of continuous growth most of the year, even a few warm days in winter calling it into bloom.

[1] If toward the end of the course there is sufficient time, it will be found helpful after completing this and the following exercise to carry on a series of studies of plants representative of the leading plant families, especially in the Angiosperms. This outline of "Shepherd's-purse" will suggest the kind of work to be done in such studies. It is understood that in most cases the students will not know the plant studied, and consequently, at the same time that they are studying the representatives of a plant family, they will also obtain some practice in determining the classification of plants. It is suggested that representatives be selected from such families as the Araceæ, Gramineæ Salicaceæ, Rosaceæ, Malvaceæ, Balsamineæ, Leguminosæ, Euphorbiaceæ, Umbelliferæ, Solanaceæ, and Convolvulaceæ.

When not flowering, the plant consists of a rosette of notched leaves lying flat upon the ground. From this rosette there arises a flowering stalk upon which are a few scattered leaves and the many small white flowers. The seed-pods are triangular heart-shaped structures that serve well to distinguish the plant from all others. The plant is most abundant in spring and early summer, but can be found in bloom throughout the warm months, and may be quite readily grown in the greenhouse for winter use.

In order to study the leading family characters as shown by this plant and to determine its classification only gross structures need be considered.

LABORATORY WORK.

I. The Plant Body. Observe:

1. The main root from which arise
2. The secondary roots.
3. The stem and its branches.
4. The leaves.
   - *a.* The rosette leaves, their general position, and their arrangement enabling all or nearly all to receive light.
   - *b.* The leaves on the upright stem, their form and size as compared with the rosette leaves. Note the differences in leaves on different parts of the stem.

II. The Flowers. Observe:

1. Calyx; size, form, and number of sepals.
2. Corolla; size, form, and number of petals. Are they alternate or opposite the sepals?
3. Stamens; size and relative length; number of cycles of

stamens and number in each cycle. Are they alternate or opposite the petals?

4. Carpels or pistils.
   a. Parts of pistil; ovary, style, and stigma.
   b. Number of chambers or cells in the ovary, as determined by a cross-section of it.
5. Whether flowers are hypogynous, perigynous, or epigynous.

III. THE SEED-POD. Observe:

1. The general form.
2. The midrib dividing it into two parts.

By dissecting it, observe:

3. The seeds (ovules), their number and how they are placed in the pod.
4. By use of manuals, beginning with the analytical key, determine the family, genus, and species of this plant.

ANNOTATIONS.

This plant has well-marked generic and specific characteristics. The leaves are distinctly notched, the basal ones being arranged into a rosette. This rosette persists through rather unfavorable seasons, and shows interesting adjustments in form and position to insure adequate exposure to the light. The leaves on the stem are younger and are small, sessile, and constantly smaller as they approach the top of the plant, probably doing but a small part of the plant's chlorophyll work.

The main root is strong and serves as a storehouse for surplus food, thus enabling the aerial organs to make rapid growth when conditions are favorable. Secondary roots arise from this primary one.

The flowers are small, the tetradynamous character

of the stamens being a striking feature. Four sepals, four petals, six stamens, and the flattened ovary more or less clearly divided into two parts serve as an excellent illustration of the leading floral characteristics in the family Cruciferæ.

SUNFLOWER.

Helianthus annuus.

SPERMATOPHYTES; DICOTYLEDONS; COMPOSITÆ.

PRELIMINARY.

THIS plant belongs to the Compositæ, which is the highest family of the plant kingdom. It is so universally recognized that no general description is needed. The species mentioned is the most common of the cultivated sunflowers, but any wild species will serve well for the study. In case it is not convenient to obtain any of the species of this genus, there are numerous representatives of the Compositæ that are good illustrations of the group. The rosinweed (*Silphium*), coneflower (*Rudbeckia*), goldenrod (*Solidago*), ox-eye daisy (*Chrysanthemum*), and dandelion (*Taraxacum*), suggest the members of the family that may be selected. If the study is to be made at a time when fresh specimens are not available either in the field or greenhouse, preserved material may be used, though the use of such material will rarely be necessary.

LABORATORY WORK.

GROSS STRUCTURE.[1]

I. The Plant Body. Observe:

1. General arrangement of parts, especially:
   a. Number of leaves.
   b. Size of leaves and length of petioles.
   c. Arrangement of leaves on the stem in order to secure proper exposure to light.
   d. The changes throughout the day in position of the tip of a plant. What function is served by the change?
2. The stem. Observe:
   a. The supporting strength.
   b. The hairs of the surface.
   c. In a transverse section observe:
      i. The central pith tissue.
      ii. The strengthening tissue.
3. The leaf. By means of surface mounts of the epidermis and cross-sections of the leaf observe:
   a. The epidermal hairs; their abundance.
   b. The number and distribution of stomata as compared with those of leaves already studied.
   c. The thickness of the cuticle, and the epidermal protection furnished to the stomata.
   d. Make drawings illustrating any structures of this leaf not seen previously.

[1] In *Helianthus* as well as in the entire family Compositæ the detailed structures of the stem, leaf, and roots, and those that have to do with the embryo-sac, fertilization, and seed formation, are essentially like those already examined in other Angiosperms. Consequently the outline does not provide for work in these parts. The composite *inflorescence*, however, offers certain peculiar advantages for study of progressive stages in the development of floral structures.

II. THE INFLORESCENCE.

The head consists of a number of more or less modified flowers borne on a common receptacle. The outer ones usually have their corollas very prominent, and distinctly unlike the corollas of the inner flowers. Observe:

1. The *involucre*, consisting of green leaf-like organs or bracts that enclose the base of the head. Observe:
   - *a.* The number of cycles of bracts.
   - *b.* The way in which they enclose young heads.
2. The *ray*-flowers, the outer ring of flowers. Observe:
   - *a.* The prominent yellow corolla, tubular at base and flattened above. The notched tips of these corollas are taken to indicate the number of petals that the united structure represents.
   - *b.* The carpel with prominent style and stigma, on whose base (ovary) the epigynous corolla seems to be borne.
   - *c.* The absence of stamens.
3. The *disk*-flowers, those occupying the part of the receptacle surrounded by the ray-flowers. Remove a few of the flowers and observe:
   - *a.* The distinctly tubular corolla with five-toothed rim (see 2 *a* above), supported by
   - *b.* The elongated ovary. Extended from the mouth of an older corolla is
   - *c.* The two-parted style and its stigmas.

   Open the corolla of a rather young disk-flower and observe:
   - *d.* The stamens with their anthers joined, thus forming a tube that adheres closely around the style (*syngenesious*).

   By studying young and old disk-flowers observe:
   - *e.* How the style elongates, forcing its tip up through the stamen-ring.

   Mount the stigmatic end of the style and observe:
   - *f.* The pollen-grains upon it.

g. The hairs by which they are held.

h. Try to determine whether these flowers are necessarily self-pollinated, by finding whether pollen is ready to be shed at the time the stigma is ripe, and by finding whether the position of parts favors self-pollination or cross-pollination.

i. Draw the disk-flowers.

ANNOTATIONS.

In the lowest group of Angiosperms the flowers are hypogynous, the floral organs are numerous, and the flowers are scattered. In higher groups there is a constant tendency toward *perigynous* (corolla around the ovary) and *epigynous* (corolla above or upon the ovary) flowers, and also toward a relatively small and regular number of floral organs in each set. Some groups lower than Compositæ have attained epigyny and definite numbers, and the Umbelliferæ (one of the highest family of Dicotyledons) have approached the Composite inflorescence, but this feature in its highest expression is the distinguishing characteristic of this great group. The form of inflorescence makes possible the production of many flowers upon a relatively small area.

The structures of the plant body of *Helianthus* indicate some of the excellent adaptations to environment so common in Compositæ, though by no means peculiar to this family. The plant is especially well adapted to living in regions of great exposure to light and heat.

In *Helianthus* the flowers are divided distinctly into ray and disk flowers. The ray-flowers are devoid of stamens, and are given over entirely to serve as showy

organs for the entire group, no seeds even being ripened within the ovaries of these flowers. The seeds are formed in the disk-flowers, one seed forming in each ovary. These conditions do not obtain for all *Compositæ*, however. In some, such as the dandelion (*Taraxacum*), all the flowers are like ray-flowers; while in some others, such as the yarrow (*Achillea millefolium*), all are tubular disk-flowers. In some, such as the rosinweed (*Silphium*) the ray-flowers mature seeds, although they have no stamens.

The *Compositæ* are remarkably successful as a group, being abundantly distributed almost everywhere during summer and autumn. They probably constitute the youngest and most successful group of plants.

GLOSSARY.*

Abstriction (act of unbinding). Partial or complete separation by contraction.

Achlorous (without green). Devoid of chlorophyll.

Alternation of generations. The alternation of gametophyte and sporophyte. Each produces a spore that upon germination produces the other generation, thus completing the life-cycle.

Anatropous (turned up). Said of an inverted ovule or seed which has the raphe extending its whole length.

Andrœcium (male household). The stamens of a flower collectively; the name was applied at a time when it was supposed that stamens were male sex-organs.

Anemophilous (wind-loving). Applied to plants that use the wind as a means of pollination.

Annulus (a ring). The elastic ring of cells around the sporangium in ferns.

Anther (flowery). The pollen-bearing part of the stamen.

Antheridium, pl. *antheridia* (anther form). The male sex-organ of the lower groups of plants.

Antherozoids. See Sperm.

Antipodal (against the foot). Said of a group of cells at the end of the embryo-sac farthest from the micropyle.

Apetalous (without petals). Applied to flowers that are devoid of specialized floral leaves.

Apical. At the apex or tip.

Apocarpous (without carpels). Applied to flowers in which the carpels are entirely free from one another.

Apophysis (an offshoot). In mosses, an enlargement of the pedicel at the base of the capsule.

* In connection with most of the terms included in the glossary there are given in parenthesis suggestions as to the original meaning of terms. In many cases such insertions help materially in understanding the terms as they are used in botany.

Archegonium, pl. *archegonia* (beginning of offspring). The female organ of Bryophytes and Pteridophytes.

Archesporium (beginning of a seed). The cell or group of cells that initiates the spore-producing series.

Areola, pl. *areolæ* (a small open space). The spaces in a reticulated surface, as in the thallus of *Marchantia*.

Ascocarp (ascus fruit). The specialized body in which asci are formed.

Ascospores (ascus seeds). The spores formed in an ascus.

Ascus, pl. *asci* (a sac or bag). The spore-sac of a large group of Fungi.

Asexual spore. A spore formed entirely independent of any cell union.

Axial. Relating or belonging to the axis.

Axil (the armpit). The angle just above the attachment of a leaf to the stem.

Axis (the pole). The central part or longitudinal support on which organs or parts are arranged.

Bast. In general, the phloëm region of a fibro-vascular bundle; or, specifically, the fibres of the phloëm.

Bract (a thin plate). The more or less modified leaves of a flower-cluster.

Bryophyta (moss-plants). A primary division of plants, named from its principal group, the mosses. *Bryophyte* is the English equivalent.

Callus (hard skin). A hardened or thickened place; technically used of the thickening mass in a sieve-plate, usually appearing as a layer on each side of the plate.

Calyptra (a cover). In mosses, the hood which covers the capsule.

Calyx (a cup). The outer envelope of a flower, composed of sepals.

Cambiform. Resembling cambium.

Cambium (exchange). The meristem cells of a fibro-vascular bundle, lying between the phloëm and xylem, which retain the power of division.

Campylotropous (turned or curved). Said of an ovule or seed which becomes curved in its growth so as to be inverted.

Capsule (a small box). A dry dehiscent seed-vessel (formed of more than one carpel); or a similar spore-vessel.

Carpel (fruit). The megasporophyll; hence either a simple pistil, or one of the parts of a compound pistil.

Carpellary. Relating to a carpel.

Carpophyta (fruit-plants). A primary division of plants, named from the sporocarp, or spore-vessel, which is the result of fertilization. *Carpophyte* is the English equivalent.

Caulicle (a small stem). The initial stem in an embryo.

Cell. The anatomical unit of plant-structure.

Cellulose (pertaining to a cell). The primary substance of the cell-wall.

Chaff. Small dry scales.

Chalaza (a pimple or tubercle). The part of an ovule where integuments and nucellus are confluent.

Chlorophyceæ (green seaweeds). The green Algæ.

Chlorophyll (leaf-green). The green coloring-matter of plants.

Cilium, pl. *cilia* (eyelash). Marginal hairs; motile protoplasmic filaments, as those of sperms.

Closed bundle. A fibro-vascular bundle containing no cambium.

Cœnocyte. A number of nucleated masses of cytoplasm (cells) enclosed within a common wall.

Collateral (sides together). Side by side; used of a fibro-vascular bundle in which the xylem and phloëm are side by side in a radial direction.

Columella (a small column). The persistent axis of certain spore-cases, as in mosses.

Concentric (center together). Technically used of a fibro-vascular bundle whose tissues are arranged concentrically.

Conidiophore (conidium-bearer). The stalk upon which conidia are borne.

Conidium, pl. *conidia* (offspring-former). The asexual spores of certain groups.

Conjugation (joined together). The sexual union of similar gametes, as in the Conjugatæ.

Connective. The portion of the stamen connecting the parts of the anther.

Corolla (a small crown). The inner envelope of a flower, within the calyx, and composed of petals.

Cortex. The rind or bark.

Cortical. Relating to the cortex or bark.

Cotyledon (a cup-shaped cavity). A primary embryo-leaf borne by the caulicle.

Cryptogams (hidden marriage). A term used to include Thallophytes, Bryophytes, and Pteridophytes.

Cupule (a little cup). The gemma-cup of liverworts.

Cuticle (the skin). The outermost layer of the epidermis, differing chemically from the remainder of the cell-wall.

Cyanophyceæ (blue seaweeds). A group of Algæ commonly known as blue-green Algæ.

Cyclic. Applied to an arrangement of leaves or floral organs in which two or more appear upon the axis at the same level, forming a cycle or whorl.

Cystocarp (bladder-fruit). The spore-fruit of some Thallophytes.

Dehiscence (gap or opening). The opening of an organ to discharge its contents, as in the case of anthers, sporangia, capsules, etc.

Dermatogen (skin-producer). The layer of nascent epidermis in the meristem of growing points.

Dichotomous (cutting in two). Forking regularly by pairs.

Dicotyledonous (cotyledons double). Having two cotyledons, or seed-leaves.

Diœcious (two households). Having the two sex-organs borne by separate individuals.

Dorsiventral. Having the two surfaces differently arranged with reference to the surroundings to which they are exposed.

Elater (a driver, or hurler). Spirally thickened cells within the sporogonia of some liverworts, which assist in expelling the spores; also special spore-distributing structures in *Equisetum*.

Egg, or oosphere. The female gamete.

Egg-apparatus. A group of three cells consisting of the egg and two synergids that lie at its sides.

Embryo (fetus, or beginning of a new individual). The young plantlet within the seed.

Embryo-sac. The cavity, within the nucellus, in which the embryo develops.

Endodermis (within the skin). The layer of cells inclosing the fibro-vascular bundle; the bundle-sheath.

Endogenous (produced within). Originating from internal tissues, and penetrating the outer ones.

Endosperm (within the seed). A parenchymatous tissue developed within the embryo-sac.

Endosperm nucleus. The nucleus formed in the Angiosperm embryo-sac by the union of two polar nuclei, one from each end of the embryo-sac.

Endospore (within the spore). The inner layer of a spore-wall.

Endothecium (within the case). The inner wall of the theca.

Entomophilous (insect-loving). Applied to those plants that use insects as means of effecting pollination.

Epidermis (upon the skin). The outermost layer of special cells covering plant-surfaces.

Epigynous (upon the ovary). Applied to those flowers whose outer parts appear to arise from the top of the ovary.

Epiphragm (a covering or lid). In mosses, a membrane covering the orifice of the capsule.

Eusporangiate (well or strong vesseled). Applied to those plants whose sporangia arise from two or more hypodermal cells.

Exogenous (produced outside). Originating from outer layers of tissue.

Exospore (outside the spore). The outer layer of a spore-wall.

Extine (on the outside). The outer coat of a pollen-spore.

Fertilization. The act of union of the sperm and the egg.

Fiber. A long and slender, thick-walled cell.

Fibrous. Composed of fibers.

Fibro-vascular (fiber-vessels). Composed of fibers and vessels; fibro-vascular bundles are the strands which make up the framework of the higher plants.

Filament (a thread). The stalk of the stamen, supporting the anther; also the individual threads of Algæ or Fungi.

Fission (splitting). Cell-division that includes the wall of the old cell.

Flowering glume. In grasses, the bract which subtends each flower, sometimes called lower palet.

Foot. A part of the sporophyte specially set apart for the purpose of absorbing nourishment.

Frond (a leaf). A name given to the leaves of ferns.

Fundamental tissue. That outside the fibro-vascular bundles and inclosed by the epidermis, but not a part of either.

Funiculus (a slender rope). The stalk of an ovule or seed.

Gametangium (gamete vessel). The specialized organ for production of gametes.

Gamete. A reproductive cell which ordinarily becomes functional only upon union with another, through which union a sexual spore is formed.

Gemma, pl. *gemmæ* (a bud). In Bryophytes, many-celled bodies specialized for asexual propagation.

Generative cell. The cell within the male gametophyte (usually within the microspore-wall) which divides to form the two male cells.

Glaucous (pale green, gray). Whitened with a bloom, like that on a cabbage-leaf.

Glume (a husk). A chaff-like bract belonging to the inflorescence of grasses; the outer glumes subtend the spikelet; the flowering glume is the bract of the flower.

Gluten (glue). A term used for the glue-like products of plants, especially of seeds.

Grain. A seed-like fruit, like those of grasses, with pericarp adnate to the seed; also any small rounded body, as of starch or chlorophyll.

Growing point. The group of meristem cells at the growing tip of an organ, from which the various tissues arise.

Gynæcium (female household). The pistil or, collective, pistils of a flower.

Haustorium, pl. *haustoria* (drinking-organs). The absorbing-organs of certain parasitic plants.

Hermaphrodite (both male and female). Having both kinds of sexual organs borne together on the same axis.

Heterogamous (having unlike gametes). Applied to plants whose pairing gametes are dissimilar.

Heterosporous (having unlike spores). Applied to plants in which the sporophyte produces two kinds of asexual spores.

Homosporous (having similar spores). Applied to plants in which the sporophyte produces but one kind of asexual spore.

Host. The plant upon which parasitic plants (or organisms) develop, and from which they derive their nourishment.

Hygroscopic (moisture-seeing). Having an avidity for water.

Hymenium (a membrane). In Fungi, a surface layer of vertical filaments containing or bearing spores.

Hypha, pl. *hyphæ* (a web). The slender vegetative filaments of Fungi which may or may not be woven into a mat (mycelium), or a plant-body.

Hypoderma (under the skin). The thick-walled tissues beneath the epidermis, which serve to strengthen it, but do not belong to the fibro-vascular bundle.

Hypogynous (being under the ovary). Applied to those flowers whose parts are at or below the base of the ovary.

Incumbent (leaning or resting upon). Said of cotyledons, when the radicle is against the back of one; of anthers, when they lie against the inner face of the filament.

Indusium, pl. *indusia* (clothing). In ferns, a cellular outgrowth of the leaf covering the clusters of sporangia (sori).

Inflorescence (flowering). The arrangement of flowers; or the flowering portion of a plant.

Integument (covering). The covering of the ovule.

Intercellular. Between or among the cells.

Internode. The part of a stem between two nodes.

Intine (on the inside). The inner coat of a pollen-spore.

Involucre (rolled within). The leaf-like or bracteate set of organs that incloses a cluster of flowers.

Isogamous (equal gametes). Applied to those plants whose pairing gametes are similar.

Lamina (a layer). The blade, or expanded part, of a leaf.

Leaf-trace. The fibro-vascular bundles from the leaf which descend into the stem, and sooner or later become blended with its fibro-vascular system.

Leptosporangiate (slender-vesseled). Applied to those plants whose sporangia arise from one superficial cell.

Ligule (a small tongue). In grasses, a thin appendage at the junction of leaf-blade and sheath.

Lodicule (a small coverlet). A small scale in the flower of grasses.

Medullary (belonging to the marrow). Relating to the pith; medullary rays are the pith-rays which pass outward to the bark between the fibro-vascular bundles.

Megaspore, or Macrospore (great or large spore). The larger one of the two kinds of asexual spores produced by certain Pteridophytes and all Spermatophytes.

Megasporangium (large spore-vessel). The sporangium that produces the megaspores.

Megasporophyll (large spore-leaf). The leaf upon which the megasporangium develops.

Meristem (dividing tissue). Tissues in a nascent or differentiating state.

Mesophyll (middle leaf). The green or soft tissue of a leaf, supported by the framework and exclusive of the epidermis, called by the older botanists parenchyma.

Micropyle (small gate). The opening left by the integuments of the ovule, and which leads to the nucellus.

Microsporangium (small spore-vessel). The sporangium that produces the microspore.

Microspore (small spore). The smaller spore of the two kinds produced by certain Pteridophytes and all Spermatophytes.

Microsporophyll (small spore-leaf). The leaf upon which the microsporangium is borne.

Midrib. The central or main rib of a leaf or thallus.

Monœcious (one household). Applied to those plants upon one of which both kinds of gametes are borne. Strictly speaking, the term applies only to the gametophyte stage of plants.

Monopodial (having one foot). Said of a stem consisting of a single and continuous axis (footstalk).

Mutualism. A symbiotic relationship where the organisms are mutually helpful.

Mother-cell. A cell that produces new cells (usually) by internal division.

Mycelium (Fungus growth). The filamentous vegetative growth of Fungi, composed of hyphæ.

Naked. Wanting some usual covering.

Nectary. The place or appendage in which nectar is secreted.

Nerve. A simple vein or rib.

Node (a joint). That part of a stem which normally bears leaves.

Nucellus (a little kernel). The mass of the ovule within the integuments.

Nucleolus (diminutive of nucleus). The sharply defined rounded part often seen in the nucleus.

Nucleus (a kernel). The usually roundish mass found in the protoplasm of most active cells, and differing from the rest of the protoplasm in its greater density.

Oogonium, pl. *oogonia* (egg-offspring). The female organ of Thallophytes.

Oophyta (egg-plants). A primary division of plants, named from the mode of reproduction, the egg-spore plants.

Oophyte is the English equivalent of Oophyta.

Oosphere (egg-sphere). The female egg-cell; the mass of protoplasm prepared for fertilization.

Oospore (egg-spore). The egg-cell after fertilization.

Open bundle. A fibro-vascular bundle which contains cambium.

Operculum, pl. *opercula* (a cover or lid). In mosses the terminal lid of the capsule.

Ovary (egg-keeper). That part of the carpel which contains the ovules.

Ovule (an egg). The body which becomes a seed after fertilization and maturation.

Palet (chaff). In grasses, the inner bract of the flower.

Palisade cells. The elongated parenchyma cells of a leaf, which stand at right angles to its surface, and are often confined to the upper part.

Palmate (pertaining to the hand.) Radiating like the fingers; said of the veins or divisions of some leaves.

Panicle (a tuft). A loose and irregularly branching flower-cluster, as in many grasses.

Pappus (down). The modified calyx of the Composites.

Paraphysis, pl. *paraphyses* (accompanying organs). Sterile bodies, usually hairs, which are found mingled with the reproductive organs of various Cryptogams.

Parasite. An organism that obtains its food from other living organisms.

Parenchyma (that which pours in beside). Ordinary or typical cellular tissue, i.e., of thin-walled, nearly isodiametric cells.

Parthenogenesis (virgin generation). The formation, without fertilization, of a spore which is functionally the same as a sexual spore. In general it means that the female gamete becomes a spore directly.

Pedicel (a little foot). The stalk upon which an organ is borne.

Peduncle (a little foot). The flower-stalk.

Pentacyclic (five cycles). Applied to flowers whose four kinds of floral organs are in five cycles.

Perianth (around the flower). The floral envelopes, or leaves of a flower, taken collectively; and an analogous envelope of the sporogonium of certain liverworts.

Periblem (a cloak). A name given to that part of the meristem at the growing point of the plant-axis, which lies just beneath the epidermis and develops into the cortex.

Pericambium (surrounding growing tissue). In roots, the external layer of the fibro-vascular cylinder.

Perichætium, pl. *perichætia* (surrounding hairs or leaves). In Bryophytes, the leaves or leaf-like parts which envelop the clusters of sex-organs, forming in some cases the so-called flower.

Perigynous (around the ovary). Applied to those flowers whose parts arise from around the wall of the ovary.

Peristome (around the mouth). In mosses, usually bristle-like or tooth-like structures surrounding the orifice of the capsule.

Perithecium, pl. *perithecia* (around the case). The spore-vessel of certain Carpophytes, containing the spore-sacs (asci).

Petal (a leaf). A corolla-leaf.

Petiole (a little foot). The stalk of a leaf.

Phanerogamia (evident marriage). A primary division (the highest) of plants, named, from their mode of reproduction, the seed-producing plants. *Phanerogam* is the English equivalent. See Spermatophytes.

Phloëm (the inner bark). The bark or bast portion of a fibro-vascular bundle.

Photosynthesis (light construction). The name applied to the process through which chloroplasts under the influence of sunlight manufacture such carbohydrates as starch and sugar from water and carbon dioxid.

Phycocyanin (blue seaweed). A bluish coloring-matter found within certain Algæ.

Phyllotaxy. Leaf-arrangement.

Pinna, pl. *pinnæ* (a feather). One of the primary divisions of a pinnate leaf, as in ferns.

Pinnule (a little feather). One of the divisions of a pinna.

Pistil (a pestle). A simple or compound carpel in Spermatophytes.

Pit. A thin place, or pit-like depression, left in the thickening of a cell-wall.

Placenta, pl. *placentæ* (a cake). That portion of the ovary which bears the ovules.

Plerome (that which fills). A name given to that part of the meristem, near the growing points of the plant-axis, which forms a central shaft or cylinder and develops into the axial tissues.

Plumule (a little feather). The terminal bud of the embryo above the cotyledons.

Pod. A dry, several-seeded, dehiscent fruit; or a similar spore-case.

Pollen (fine flour). The spores developed in the anther.

Pollen-tube. The structure that develops from the wall of the microspore on Spermatophytes and carries male cells to the egg.

Pollination. The transfer of pollen to the stigma.

Polypetalous (many petals). Applied to flowers that have their petals free from one another.

Proembryo (going before the embryo). In Spermatophytes, the chain of cells (suspensor) formed after fertilization, and from the lower end of which the embryo develops See Suspensor.

Prothallium, pl. *prothallia* (a forerunning shoot). The small, usually short-lived plant which develops from the spore and bears the sex-organs.

Protonema, pl. *protonemata* (that which is first sent out). In mosses, the filamentous growth which is produced by the spores, and from which the leafy moss-plant is developed.

Protophyta (the first plants). A primary division of plants named from the fact that they include the lowest known plants. *Protophyte* is the English equivalent.

Protoplasm (that which is first formed). The living matter of cells.

Pteridoid. Fern-like.

Pteridophyta (fern-plants). A primary division of plants, named from its principal group, the ferns. *Pteridophyte* is the English equivalent.

Pyrenoid (kernel-formed). Minute colorless bodies imbedded in the chlorophyll structures of some lower plants.

Raphides (needle-formed). Needle-like plant-crystals.

Receptacle. That portion of an axis or pedicel (usually broadened) which forms a common support for a cluster of organs, either sex-organs or sporophylls.

Reticulated (net-like). Having a net-like appearance.

Rhachis (the backbone). The axis of a compound leaf, or of a spike.

Rhaphe (a seam). In an anatropous ovule, the ridge which connects the chalaza with the hilum.

Rhizoid (root-formed). Root-like; a name applied to the root-like hairs found in Bryophytes and Pteridophytes.

Rhizotaxy. Root-arrangement.

Root-stock. A horizontal, more or less thickened, root-like stem, either on the ground or underground.

Saprophyte (rotten plant). Organisms that obtain their food from dead or decaying organisms.

Scalariform (ladder-form). A name applied to ducts with pits horizontally elongated and so placed that the intervening thickening ridges appear like the rounds of a ladder.

Scale (a flight of steps). Any thin scarious body, as a degenerated leaf, or flat trichome.

Sclerenchyma (a hard infusion). A tissue belonging to the fundamental system and composed of cells that are thick-walled, often excessively so.

Scutellum (a small dish). The disk-like or shield-like cotyledon of grasses.

Seed. The matured ovule.

Sepal. A calyx-leaf.

Seta, pl. *setæ.* A bristle, or bristle-shaped body; in mosses, the stalk of the capsule.

Sexual spore. One formed by the union of cells.

Sheath. A thin enveloping part, as of a filament, leaf, or resin-duct.

Sieve-cells. Cells belonging to the phloëm, and characterized by the presence of circumscribed and perforated panels in the walls; the panels are *sieve-plates*, and the perforations *sieve-pores*.

Sorus, pl. *sori* (a heap). In ferns, the groups of sporangia, constituting the so-called "fruit-dots"; in parasitic Fungi well-defined groups of spores, breaking through the epidermis of the host.

Sperm, or Spermatozoid (animal-like sperm). The male gamete.

Spermatophytes (seed-plants). The highest great group of plants, of which a characteristic structure is the seed.

Spike (an ear of corn). A flower-cluster, having its flowers sessile on an elongated axis.

Spikelet (diminutive of spike). A secondary spike; in grasses, the ultimate flower-cluster, consisting of one or more flowers subtended by a common pair of glumes.

Sporangium, pl. *sporangia* (spore-vessel). The spore-producing structure.

Spore (seed). Originally used as the analogue of seed in flowerles plants; now applied to any one-celled or few-celled body which is separated from the parent for the purpose of reproduction, whether sexually or asexually produced; the different methods of its production are indicated by suitable prefixes.

Sporogonium, pl. *sporogonia* (spore-offspring). The whole structure of the spore-bearing stage of Bryophytes.

Sporophyll. A leaf that bears sporangia.

Sporophyte (spore-plant). The asexual or spore-producing stage of an alternating plant.

Stamen (the warp, or thread, of cloth). The microsporophyll in Spermatophytes.

Stigma (a spot or mark). The surface of a pistil without epidermis which receives the pollen.

Stigmatic. Relating to the stigma, or stigma-like.

Stoma, pl. *stomata* (a mouth). Epidermal structures which serve for facilitating gaseous interchanges with the external air, and for transpiration of moisture. They are often called "breathing-pores."

Strobilus. A cone-like cluster of sporophylls.

Strophiole (a small wreath). An appendage at the hilum of certain seeds.

Style (a pillar). The usually attenuated portion of the pistil which bears the stigma.

Suspensor. A chain of cells which develops early from the oospore and serves to push the embryo-cell deep within the embryo-sac.

Symbiont. One of the organisms that has entered into a symbiotic relationship.

Symbiosis (living together). Applied to a condition where two or more organisms are living in an intimate relationship.

Syncarpous (carpels united). Applied to those conditions where the carpels have united into a compound pistil.

Synerigdæ, or Synergides (helpers). The two nucleated bodies which accompany the oosphere in the embryo-sac, and together with it form the egg-apparatus.

Testa (a shell). The outer seed-coat.

Tetracyclic (four cycles). Applied to those flowers in which there are four cycles of floral organs.

Tetradynamous (four-strong). Said of an andrœcium in which there are four long and two shorter stamens.

Thalloid. Thallus-like.

Thallus (a young shoot). The body of lower plants, which exhibits no differentiation of stem, leaf, and root.

Theca, pl. *thecæ* (a case). The "anther-cell," that is, the case containing pollen; sometimes used of other spore-cases.

Tracheary tissue. A general name given to the vessels and ducts found in fibro-vascular bundles.

Tracheides (rough-formed tissues). Tracheary cells that are closed throughout.

Trichogyne. A hair-like extension from the bulbous portion of the oogonium, found in many red Algæ.

Trichome (a hair). A general name for a slender outgrowth from the epidermis, usually arising from a single cell.

Turgidity. The normal swollen condition of active cells which results from the distension brought about by absorption of water.

Vein. The fibro-vascular bundle of leaves or any flat organ.

Venation. The mode of vein-distribution.

Xylem (wood). The wood (inner) portion of the fibro-vascular bundle.

Zoospore (animal spore). A motile asexual spore.

Zygomorphic. Said of a flower which can be bisected by only one plane into similar halves.

Zygophyta (yoke-plants). A primary division of plants, now commonly spoken of as Conjugatæ, named from their mode of reproduction, the sexual spore being produced by conjugation. *Zygophyte* is the English equivalent.

Zygospore (yoke-spore). The spore of Conjugatæ, formed by conjugation.

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